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THE BRIDGEWATER TREATISES,

ON THE POWER, WISDOM, AND GOODNESS OF GOD, AS MANIFESTED IN THE CREATION.

TREATISE VIII.

CHEMISTRY, METEOROLOGY, AND THE FUNCTION OF DIGESTION.

BY WILLIAM PROUT, M.D. F.R.S.

Μὴ ὑπαρχούσας γάρ ἁρμονίας, καὶ ἘΠΟΨΙΟΣ ΘΕΙ'ΑΣ περὶ τὸν κόσμον οὐκ ἂν ἐδύνατο συνεῖμεν ἔτι καλῶς ἐχοντα τὰ ἐγκεκοσμαμένα.

HIPPODAMUS DE FELICITATE.

CHEMISTRY, METEOROLOGY,

AND

THE FUNCTION OF DIGESTION,

CONSIDERED WITH

REFERENCE TO NATURAL THEOLOGY.

BY

WILLIAM PROUT, M.D. F.R.S.

FELLOW OF THE ROYAL COLLEGE OF PHYSICIANS.

PHILADELPHIA:

CAREY, LEA & BLANCHARD.

1834.

TO

DAVIES GILBERT, ESQ.

LATE PRESIDENT OF THE ROYAL SOCIETY,

This Volume

IS

RESPECTFULLY INSCRIBED.

NOTICE.

THE series of Treatises, of which the present is one, is published under the following circumstances:

The RIGHT HONOURABLE and REVEREND FRANCIS HENRY, EARL of BRIDGEWATER, died in the month of February, 1829; and by his last Will and Testament, bearing date the 25th of February, 1825, he directed certain Trustees therein named to invest in the public funds the sum of Eight thousand pounds sterling; this sum, with the accruing dividends thereon, to be held at the disposal of the President, for the time being, of the Royal Society of London, to be paid to the person or persons nominated by him. The Testator further directed, that the person or persons selected by the said President should be appointed to write, print, and publish one thousand copies of a work *On the Power, Wisdom, and Goodness of God, as manifested in the Creation; illustrating such work by all reasonable arguments, as for instance the variety and formation of God's creatures in the animal, vegetable, and mineral kingdoms; the effect of digestion, and thereby of conversion; the construction of the hand of man, and an infinite variety of other arguments; as also by discoveries ancient and modern, in arts, sciences, and the whole extent of literature.* He desired, moreover, that the profits arising from the sale of the works so published should be paid to the authors of the works.

The late President of the Royal Society, Davies Gilbert, Esq. requested the assistance of his Grace the Archbishop of Canterbury and of the Bishop of London, in determining upon the best mode of carrying into effect the intentions of the Testator. Acting with their advice, and with the concurrence of a nobleman immediately connected with the deceased, Mr. Davies Gilbert appointed the following eight gentlemen to write separate Treatises on the different branches of the subject as here stated:

THE REV. THOMAS CHALMERS, D. D.

Professor of Divinity in the University of Edinburgh.

ON THE POWER, WISDOM, AND GOODNESS OF GOD AS MANIFESTED IN THE ADAPTATION OF EXTERNAL NATURE TO THE MORAL AND INTELLECTUAL CONSTITUTION OF MAN.

JOHN KIDD, M. D. F. R. S.

Regius Professor of Medicine in the University of Oxford.

ON THE ADAPTATION OF EXTERNAL NATURE TO THE PHYSICAL CONDITION OF MAN.

THE REV. WILLIAM WHEWELL, M.A. F.R.S.

Fellow of Trinity College, Cambridge.

ASTRONOMY AND GENERAL PHYSICS CONSIDERED WITH REFERENCE TO NATURAL THEOLOGY.

SIR CHARLES BELL, K.G.H. F.R.S. L.&E.

THE HAND: ITS MECHANISM AND VITAL ENDOWMENTS AS EVINCING DESIGN.

PETER MARK ROGET, M.D.

Fellow of and Secretary to the Royal Society.

ON ANIMAL AND VEGETABLE PHYSIOLOGY.

THE REV. WILLIAM BUCKLAND, D.D. F.R.S.

Canon of Christ Church, and Professor of Geology in the University of Oxford.

ON GEOLOGY AND MINERALOGY.

THE REV. WILLIAM KIRBY, M.A. F.R.S.

ON THE HISTORY, HABITS, AND INSTINCTS OF ANIMALS.

WILLIAM PROUT, M.D. F.R.S.

CHEMISTRY, METEOROLOGY, AND THE FUNCTION OF DIGESTION, CONSIDERED WITH REFERENCE TO NATURAL THEOLOGY.

His Royal Highness the Duke of Sussex, President of the Royal Society, having desired that no unnecessary delay should take place in the publication of the above mentioned treatises, they will appear at short intervals, as they are ready for publication.

TO THE READER.

CHEMISTRY has not hitherto been considered in detail with reference to Natural Theology: the difficulties, therefore, incidental to a first attempt, added to those arising from the nature of Chemistry itself as a science, must be the apology of the author for numerous imperfections in this treatise.

The peculiar chemical opinions advanced, would never have appeared in their present form; had not the author been strongly impressed with the belief that they are calculated, sooner or later, to bring chemical action under the dominion of the laws of quantity; and had he not despaired, under his professional engagements, of being himself able to submit them to experimental proof. These opinions, however, have been always introduced as mere illustrations.

The argument of design is necessarily cumulative; that is to say, is made up of many similar arguments. To avoid repetitions therefore, the illustration of principles rather than of details, has been studied; and the application of particular facts to the argument, has been often left to the Reader.

LONDON,
February 3, 1834.

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INTRODUCTION.

OF THE LEADING ARGUMENT OF NATURAL THEOLOGY; THAT DESIGN, OR THE ADAPTATION OF MEANS TO AN END, EXISTS IN NATURE.

With the view of illustrating the argument of design, we shall commence with a statement of that argument in its simplest form.

Animals in cold climates have been provided with a covering of fur. Men in such climates cover themselves with that fur. In both cases, whatever may have been the end or object, no one can deny that the *effect*, at least, is precisely the same: the animal and the man are alike protected from the cold. Now, since the animal did not clothe itself, but must have been clothed by another; it follows, that whoever clothed the animal, must have known what the man knows, and must have reasoned like the man; that is to say, the clother of the animal must have known that the climate in which the animal is placed, is a cold climate; and that a covering of fur, is one of the best means of warding off the cold; he therefore clothed his creature in this very appropriate material.

The man who clothes himself in fur to keep off the cold, performs an act directed to a certain end; in short, an act of *design*. So, whoever, directly or indirectly, caused the animal to be clothed with fur to keep off the cold, must likewise have performed an act of *design*.

But, under the circumstances, the clother of the animal, must be admitted to have been also the *Creator* of the animal; and by extending the argument; the Creator of man himself—of the universe. Moreover, the reasoning the Creator has displayed in clothing the animal, He has designed to impart to man, who is thus enabled to recognize his Creator's design.

Such is an instance of those varied adaptations of means to ends around him, which man by his reasoning, appreciates; and which demonstrate to him, the existence of an intelligent Creator. Compared, however, with the extent of creation, the instances, nu-

merous as they appear, in which man is thus able to trace the designs of his Creator, are really few. Man not only sees means directed to certain ends ; but ends accomplished by means, which he is totally unable to understand. He also sees, every where, things, the nature, and the end of which are utterly beyond his comprehension; and respecting which, he is obliged to content himself with simply inferring the existence of design.

The argument of design, therefore, in its general sense, embraces at least three classes of objects :—

1. Those objects, regarding which, the reasoning of man coincides with the reasoning evinced by his Creator ; as in the simple adaptation of clothing above mentioned: or those objects, in which, man is able to trace, to a certain extent, his Creator's designs ; as in various phenomena amenable to the laws of quantity; viz. mechanics, &c.

2. Those objects, in which, man sees no more than the preliminaries and the results, or the end and design accomplished ; without being able to trace through their details, the means of that accomplishment; as in all the phenomena and operations of chemistry.

3. Those objects, in which, design is inferred, but in which the design, as well as the means by which it is accomplished, are alike concealed; as in the existence of fixed stars, of comets, of organized life ; and indeed in all the great and more recondite phenomena of nature.

The intention of these Treatises, is to point out the various evidences of design, among the objects of creation ; and to deduce from them, the existence, and the attributes, of the Creator. The following pages are occupied more particularly, with the illustration of the evidences of design, in objects belonging to the second of the three classes above mentioned; with those, namely, in which design is obvious, though we cannot trace the means by which that design is accomplished.

BOOK I.

OF CHEMISTRY.

PRELIMINARY OBSERVATIONS ON THE RANK OF CHEMISTRY AS A SCIENCE; AND ON ITS APPLICATION TO THE ARGUMENT OF DESIGN.

"CHEMISTRY does not afford the same species of argument (in favour of design) that mechanism affords, and yet may afford an argument in a high degree satisfactory."* This remark of the excellent Paley has been made by him with reference only to a particular subject, but the following sketch, pointing out the grounds upon which chemistry as a science is founded, and the rank which it holds among the departments of human knowledge, will at the same time show the general truth of the remark.

An elaborate inquiry into the origin and nature of human knowledge would be quite misplaced here. We shall content ourselves with simply considering it as of two kinds, viz: a knowledge of what *must be;* that is to say of what we cannot conceive either not to exist, or to exist otherwise than as it is, and which is therefore founded upon reason; and a knowledge of what simply *is*, but how or why we know not, and for the existence of which, therefore, we can assign no reason but our experience alone.

Of these, the only instance of the first kind which particularly concerns us at present, is the knowledge of *quantity* and its relations in general; of the second, that of certain natural phenomena, the consideration of which constitutes the principal object of the present volume.

The fundamental differences between these two great branches of human knowledge, as well as their consequences, cannot perhaps be more strikingly illustrated than in the following familiar exposition by a celebrated writer. "A clever man," says Sir J. Herschel, "shut up alone and allowed unlimited time, might reason out for himself all the truths of mathematics, by proceeding from those simple notions of space and number of which he cannot divest himself without ceasing to think; but he would never tell by any effort of reasoning what would become of a lump of sugar, if immersed in water, or what impression would be pro-

* Natural Theology, chap. vii.

duced on his eye by mixing the colours yellow and blue,"* results which can be learnt only from experience.

Thus then the extremes of human knowledge may be considered as founded on the one hand purely upon reason, and on the other purely upon sense. Now, a very large portion of our knowledge, and what in fact may be considered as the most important part of it, lies between these two extremes, and results from a union or mixture of them, that is to say, consists of the application of rational principles to the phenomena presented by the objects of nature.

With respect to knowledge founded upon *reason*, we are so constituted, that whether we contemplate those primary notions of space, time, force, &c. above alluded to in the abstract, or whether we view them in connexion with the objects of sense around us, we cannot divest them of *quantity*, which seems to be involved in their very essence. Quantity and its relations, therefore, in some shape or other, enter as a necessary element into by far the greater portion of human knowledge. Now the primary relations of quantity are exceedingly simple; one quantity may be equal to another, or it may be greater or less, but we can conceive no other relation. Hence all the operations of the mathematics—the science of quantity and its relations—however abstruse and complicated they appear, can be ultimately resolved into addition and subtraction.

It is principally then through the medium of the relations of quantity that we are enabled to reason in a satisfactory manner upon the objects of sense. For as everything in nature, or what is the same thing to us, every sensation produced by one natural object, as compared with that produced by another, must be either equal or similar, or unequal or dissimilar; the whole are capable of being subjected, more or less perfectly, to the laws of quantity. This is effected in various ways and by various artifices, but chiefly through the intervention of certain natural or assumed units, or standards of resemblance, as a second in time, a foot in space, &c., and in proportion to the definite character of these units, or standards, and as they can be more or less satisfactorily applied, so will the resulting branch of knowledge be more or less of a mathematical character, or be more or less rational and perfect.

By contemplating, in the abstract, the boundless relations of time and of space, where no end can be conceived to addition and subtraction, we arrive at the only notions of infinity of which our nature seems capable. These once obtained, the obvious and ne-

* Discourse on the Study of Natural Philosophy, p. 76.

cessary existence of cause within the narrow sphere of our observation naturally leads us to inquire, can this cause be infinite? And thus we are led by degrees, but irresistibly, to the sublimest of all conclusions, that a Cause or Agent in every way commensurate with infinity—omniscient and omnipresent, eternal and omnipotent must exist—in other words, a God.

Compared with infinity, however, and even with the objects of nature as they visibly exist around us, our actual knowledge of time and of space is exceedingly limited. Like travellers on an extended plain, we see what is going on around us at the present moment, but the distant and the very near, the past and the future, are alike unknown to us. A few millions of miles, for example, or a few thousand years, comprise the utmost that we know of space and of time. On the other hand, beyond the fraction of an inch, or of a second, everything belonging to space and to time is inappreciable by our senses. Yet beyond these limits we *know* that myriads of portions of space and of time must exist, too vast or too minute to be referred to our imperfect standards. Let us, for instance, take the distance of the nearest fixed star. This we are assured by astronomers is so great that the utmost measure we can apply to it—the diameter of the earth's orbit—a space of no less than 192,000,000 of miles is absolutely too little to measure it by—is in fact contained within it so many times that the number cannot at present be counted! On the other hand, we shall presently find, that the molecules of matter of which the objects we see around us are composed are so minute, that a measure scarcely appreciable by the unassisted sight, the thousandth part of an inch for example, is vastly too large to compare them with, and may in fact comprise millions of them!

Experience, the great and ultimate source of all the knowledge we possess of those portions of nature to which our faculties are limited may be acquired in two ways; by simple observation, and by experiment; that is to say, either "by noticing facts as they occur without any attempt to influence the frequency of their occurrence, or to vary the circumstances under which they occur;" or "by putting in action causes and agents over which we have control, and purposely varying these combinations, and noticing what effects take place."* Now in all the higher departments of knowledge the objects of which are principally matter, and its motions in the aggregate, the information we can acquire by one or both these means is so complete, and at the same time so favourable to the application of the relations of quantity, that the resulting sciences have all the certainty of abstract truths

* Herschel's Discourse on the Study of Natural Philosophy, p. 76.

themselves. But when the knowledge we possess of objects is wholly sensible, and in no way commensurate, or only very imperfectly so with their quantity, here it is that uncertainty begins; for though we may be able to trace the apparent *cause* and *effect* of a particular phenomenon, the most minute and careful observation and experiment, often give us but little insight into the connexion between the two, and generally fail us altogether. The reason of this is to be sought for in the limited nature of our faculties, and particularly in our complete ignorance of the nature of that mysterious communication which we maintain with the external world through the medium of sensation. In two of the senses indeed, *seeing* and *hearing*, we are able to trace the intermediate train of phenomena between the external object producing the sensation and the sensation itself, and even to form some idea of the remote cause of the sensation; but in the other two senses, *tasting* and *smelling*, the whole is involved in mystery from beginning to end.

Thus when a bell is struck, philosophers have satisfactorily demonstrated that a vibratory motion, excited in the bell, and depending upon its elasticity, is communicated to the air in contact with it, and through this medium is propagated to the ear, in which organ, we know not why, the sensation of sound is excited. Circumstances very similar have been supposed to take place with respect to light, and *undulæ* (or something obeying the laws of *undulæ*) have been demonstrated to exist and to be propagated from the luminous body to the eye, and thus the remote cause of sound, and probably of light, is proved to be motion. But in the cases of *tasting* and *smelling* the circumstances are altogether dissimilar; here the sapid and odoriferous matters are brought at once into actual contact with the sentient organs, and the sensations are the consequence without any intermediate train of phenomena, at least any that we can appreciate. What it is therefore in an acid or a rose for example, analogous to motion in the bell, and which produces the sensations we call *sour* and *sweet* we know not, and probably never shall know, and simply because the laws and relations of quantity are here either totally inapplicable, or can be only indirectly and most imperfectly applied.

These observations are principally introduced with reference to the department of knowledge we have at present to consider. Almost all of what are denominated the *chemical* properties of bodies, are objects of taste and of smell, rather than of sight and of hearing. Hence they admit only of the indirect application of the laws of quantity, and are the result, not of reason but solely of experience. Indeed, so much is chemistry the creature of actual experimental research, that its simplest truths have seldom been

anticipated *a priori*. Thousands of years of observation and experience for example had not taught mankind that water is composed of two elementary gaseous principles, much less the proportions in which those principals combine to form water. Nay, even now the fact has been established upon the clearest evidence, we are unable to explain why it is so, or even to comprehend the nature of the union or its result. Hence, to use the language of Paley, in all chemical operations—" our situation is precisely like that of an unmechanical looker-on, who stands by a machine, the fabric of which is hidden from his sight by the outside case, or if seen, would be too complicated for his uninformed understanding to comprehend. And what," continues this energetic writer, " is that situation ? Ignorant as he is, he does not fail to see that certain materials, in passing through the machine, undergo remarkable changes ; and what is more, changes manifestly adapted for future use. Is it necessary that this man, in order to be convinced that design, that intention, that contrivance, have been employed about the machine, should be allowed to pull it to pieces to study its construction ? He may indeed wish to do this for many reasons, but for all the purposes of ascertaining the existence of counsel and design in the formation of the machine, he wants no such intromission or privity. What he sees is sufficient. The effect upon the material, the change produced in it, the utility of that change for further applications abundantly testify, be the concealed part of the machine, or of its construction what it will, the hand and agency of a contriver."*

We have thus attempted to point out the rank which chemistry holds among human knowledge, and the kind of evidence which it furnishes in favour of design ; and the whole argument may be briefly recapitulated as follows : chemistry is a branch of knowledge founded solely on experience, for the phenomena of which we can assign no reason. But although the intimate nature of its changes be unknown to us, we see them manifestly directed to certain ends ; hence as objects directed to certain ends, where the whole of the intermediate phenomena can be traced and understood, always imply design, we naturally infer design in others obviously so directed, even although we may not be able to understand their intimate nature.

Such is the state in which Paley has left the argument, and while we admit that even in its most perfect form, it is less satisfactory than that founded upon mechanism, we have always thought that our excellent author has not made quite so much of his subject as he might have done, and that the very imperfections

* Natural Theology, chap. vii. condensed slightly, but the argument strictly adhered to.

and difficulties of chemistry and of the allied branches of knowledge give them some advantages over mechanism itself. When a series of wheels or of levers are arranged in a certain order, they *must* move in a certain way, and produce a certain effect which can be foretold exactly. In such a case, we may admire the skill and ingenuity of the Contriver, or perhaps feel astonished at his power, but we scarcely do more, and much of the effect is lost in the apparent necessity of the result, and the consciousness that under the circumstances nothing else could have happened. When the Deity, therefore, operates through the medium of mechanism, he appears almost too obviously to limit his powers within the trammels of necessity; but when he operates through the medium of chemistry, the laws of which are less obvious, and indeed for the most part unknown to us, his operations have much more the character of those of a free agent, and, in many instances also, appear of a higher order, and are more striking and wonderful. Do not, for instance, those extraordinary and mysterious changes constantly going on around us, beneath us, within us, derive no small additional interest from the very circumstance of their not being understood? Just such an interest, to revert to the argument of Paley, as the unmechanical looker-on feels in the operations of a corn-mill, a carding-machine, or a threshing-machine, and to which he who is well acquainted with the mechanism is a stranger. Certainly this is the case. Obvious mechanism, though well suited to display the intelligence and design of the Contriver, is not always so well adapted for arresting the attention of the observer; its very obviousness in some measure depriving it of its interest. But when we see the same Contriver, besides the most beautiful and complicated mechanism, employ other means utterly above *our* comprehension, though evidently most familiar to *him*, the circumstance is not only calculated to arrest our attention more forcibly, but at the same time to impress us with more exalted notions of his wisdom and power.

There yet remain one or two other points to be briefly considered before we proceed to our subject. In the first place it may be asked, do those extraordinary changes which appear to be constantly going on in bodies around us, indicate real and substantial changes in the bodies themselves, or are they mere phantasms and creations of the organs of sense, through which we become acquainted with them? The discussion of this question will probably be considered by most as superfluous, but for the sake of those (if there be any) who entertain doubts upon the point, it may be remarked, that the sensations, though admitted to be mere signals or indications, bearing little or no analogy with the causes producing them, and therefore throwing little light up-

on their nature, do nevertheless represent real and substantial operations of some sort in the bodies themselves. This might be proved were it necessary by a variety of arguments, but one or two only will be sufficient for our present purpose. In the first place it may be stated, that changes in the chemical constitution of bodies are usually accompanied by corresponding changes in *weight*. Now weight is a modification of *force*, one of those self-evident existences which we cannot doubt without doubting our own. Another, and perhaps indeed the most striking argument in favour of the reality of chemical changes, may be deduced from the subserviency to them of those mechanical contrivances and operations everywhere existing in organized beings. At least, half the mechanism in a living animal is subservient to the chemical changes constantly going on in it, and necessary to its existence. Take, for instance, the circulation of the blood: what a complicated apparatus is here employed for the simple purpose of exposing the blood to the action of the air in the lungs, in order that it may there undergo some chemical change. Now, surely no one can reasonably doubt that this chemical change is as much a reality as the mechanism by which it has been accomplished; and if *one* chemical change be admitted to be a reality, why may not all others?

Lastly, if there be any one who denies the existence of design, and sees nothing in all the more obvious arrangements and order around him but the necessary results of what he chooses to denominate "the laws of nature," let him calmly and deliberately consider the facts brought forward in the following pages; and if he can witness unconvinced all the numerous instances of prospective arrangement obviously made with reference to things not yet in existence; all the beautiful adjustments and adaptations of noxious and conflicting elements most wonderfully conspiring together for good; and, lastly, the subversion of even his favourite "laws of nature" themselves, when a particular purpose requires it; if, we say, he can witness all these and still remain incredulous of the evidences of design, we can only observe, that his mind must be most singularly constituted, and apparently beyond the reach of conviction.

CHAPTER I.

OF THE MUTUAL OPERATION OF PHYSICAL AGENTS AND OF MATTER, AND OF THE LAWS WHICH THEY OBEY.

"God has been pleased to prescribe limits to his own power, and to work his ends within those limits. The general laws of matter have perhaps the nature of these limits; its *inertia*, its reaction, the laws which govern the communication of motion, of light, of heat, of magnetism and electricity, and probably of others yet undiscovered. These are general laws, and when a particular purpose is to be effected, it is not by making them wind and bend and yield to the occasion, (for nature with great steadiness adheres to and supports them,) but it is, as we have seen in the eye, by the interposition of an apparatus corresponding with these laws, and suited to the exigency which results from them, that the purpose is at length attained. As we have said, therefore, God prescribes limits to his power, that he may let in the exercise, and thereby exhibit demonstrations of his wisdom. For then, *i. e.* such laws and limitations being laid down, it is as though one Being should have fixed certain rules; and, if we may so speak, provided certain materials; and afterwards have committed to another Being, out of these materials, and in subordination to these rules, the task of drawing forth a creation: a supposition which evidently leaves room, and induces indeed a necessity for contrivance. Nay, there may be many such agents, and many ranks of these."* This admirable passage from Paley is so much in point, and so exactly expresses our views upon the subject, that we have chosen it as a text, as in a former instance, for illustration. We shall proceed, therefore, to take a summary view of "the limits within which the Deity has confined his operations;" that is to say, of the laws by which matter, and these subordinate agents by which it is capable of being influenced, have been made to mutually act and react upon each other.

The principles of activity which operate as subordinate agencies in nature may be considered as of two kinds; those which operate universally upon every individual atom of matter without reference to its sensible properties, as the forces producing the phenomena of *gravitation*, &c.; and those which operate among the different constituent molecules of which all bodies are composed, and which are denominated *molecular* or *polarizing* forces, &c. Of each of these we shall in the first place endeavour to convey some idea to the general reader.

* Natural Theology, chap. iii.

CHAPTER II.

ON THE INERTIA AND ACTIVITY OE MATTER.

To form a notion of what is termed the *inertia* or inactivity of matter, let us imagine a portion of it, as for example, a ball of lead A detached from all other matter, and existing absolutely uninfluenced in space. Such a mass of matter, if supposed to be at rest, must obviously remain so, for it cannot move itself; on the other hand, if it be supposed to be in motion, it must continue in motion, for it cannot be conceived to be able to stop itself any more than it could be conceived to be able to set itself in motion; in short, a mass of matter under such circumstances of isolation must be considered as perfectly passive and unable to change its state, whatever that may happen to be, whether of motion or of rest. Now let us suppose another portion of matter, as for example, another ball of lead B exactly of the same size as A, placed in free space at any moderate distance from A, and away from all other influences, what will happen? We know from general experience that under these circumstances, the two balls will mutually approach each other with an accelerated motion, till they meet at a point exactly intermediate from those at which they first started; and the inference from this experience is, that the two balls exert a mutual and equal attractive force, which causes them to move towards each other. If the ball B be twice the size of the ball A, the two balls will mutually approach each other as before, but, in this instance, instead of moving with equal velocity, while the ball A moves two feet, the ball B will only move one foot; or taking an extreme case, and supposing the ball B to be indefinitely larger, say a million times larger, than the ball A, they will mutually influence and mutually move towards each other as before, but the motion of the ball B will be so minute as to be insensible, while that of the ball A will be the greatest possible. Here we have instances of the *inertia* (inactivity, opposing force, &c.) and of the activity (force of attraction, force of gravitation, &c.) which all matter exerts reciprocally and mutually towards all other matter, and the laws of which, as deducible from the circumstances stated, and from others, which it would be foreign to our present purpose to enter upon, may, in general terms, be given as follows: "The mutual attraction of two bodies increases in the same proportion as their masses are increased, and as the square of their distance is decreased, and it decreases in proportion as their masses are decreased and as the

square of their distance is increased." These laws, and those of the motions connected with them, are absolutely general, and not only extend to the utmost limits of the universe hitherto explored by man, but to every form and condition of matter, without exception and without reference to its other properties. They, therefore, constitute, probably, the most comprehensive "limits which the Deity has been pleased to prescribe to His power," and within which He operates with the most unceasing and undeviating regularity and certainty; they have also the remarkable property of being so amenable to the laws of quantity and mathematics, as to be in most instances as firmly established upon reason as abstract truths themselves. The mind of a Newton was chosen to reveal these laws to man, and man's acquaintance with them may be justly considered as one of his noblest privileges. To point out their wonders in detail, and the sublime conclusions to which they lead, is the business of a colleague; at present we have to consider them in their more general form only, and, except in a single point of view, as objects of comparison merely with those more immediately connected with our own subject.

The point of view to which we allude is that peculiar case, or instance of gravitating force, termed *weight*. In our illustration of the attractive forces of matter above given we supposed a case in which one ball was very much larger than the other: now this precisely corresponds with the case of the globe of the Earth, and of all common bodies near its surface. The earth is more than 1,000,000,000,000,000 times the mass of any body which is observed to fall on its surface, and therefore if even the largest body which can come under observation were to fall through a height of 500 feet, the corresponding motion of the Earth would be through a space less than the 1,000,000,000,000,000th part of 500 feet, which is less than the 100,000,000,000th part of an inch, and therefore quite inappreciable.* Now the attractive force exerted between the earth and detached bodies is denominated *weight*. Hence the weight of a body, at the earth's surface, is proportionate to its mass, or to the quantity of matter it may contain, whatever its form or qualities may be—a most important fact for the chemist, who, by employing the chemical properties of bodies as indications of identity or of change, is by these means enabled to apply to them the more certain measure of *weight*, and thus in some degree to bring them under the dominion of the laws of quantity.

* Lardner's Cabinet Cyclopædia, Art. Mechanics, p. 79.

CHAPTER III.

OF MOLECULAR OR POLARIZING FORCES, ETC.

In all chemical operations, as already observed, we only witness the beginning and the end, the cause and the effect, while the whole of the intermediate changes elude our senses. Nevertheless, by a careful observation of the phenomena we are enabled to form some notion upon the subject, and that amply sufficient to convince us of their wonderful nature. With a view therefore of arresting the attention of those who may be unconscious of these wonders, or too apt to overlook them, we have thought it proper to premise a sketch of what may be supposed to take place among the ultimate particles of which all bodies are constituted, during those remarkable changes which they are constantly undergoing. And here it may be remarked, once for all, that many of the views commonly entertained on these points have always appeared to us to be so imperfect and unsatisfactory, that so far from elucidating the subject, they have only served to render it the more obscure. In the following sketch, therefore, as better adapted for our purpose, we have endeavoured to give that view of the subject, which, after twenty years of close attention and no ordinary labour, we have been induced to consider as the most simple and consistent with the phenomena. The general reader, who feels no interest in these inquiries, and who at the same time wishes to be apprized of the nature of the arguments deducible from the divisibility and molecular constitution of matter, is referred to the end of the present and of the following chapters for a summary of these arguments.

SECTION I.

Of the Divisibility of Matter.

The first point which naturally claims our attention in the consideration of molecular operations, is the *size* of these molecules; a subject usually discussed under the head of the divisibility of matter. Matter, or rather space, may be conceived to be divisible *ad infinitum;* at least no limits can be assigned beyond which its subdivision cannot necessarily proceed. As however, it exists in the world around us, there cannot be the least doubt that it is composed of ultimate particles or molecules inca-

pable of further division or change, at least by ordinary agents: the reasons for these assertions will appear hereafter, at present it is our object to convey to the general reader some idea of the magnitude of these particles, with the view, principally, of showing how infinitely they surpass the limited powers not only of our senses, but almost of our conception. The subject, however, has so much attracted the attention of philosophers, that most of our readers must be already familiar with it; we shall therefore content ourselves with merely selecting a single instance from each of the kingdoms of nature. As an instance from the mineral kingdom, we may quote from Dr. Thomson, who has shown that an ultimate molecule of lead cannot weigh more than the $\frac{1}{3100000000000}$ th, nor an ultimate molecule of sulphur more than $\frac{1}{2015000000000}$ th of a grain, and probably a great deal less; and that the *size* of the molecule of lead cannot surpass, and is probably much less than the $\frac{1}{88849200000000}$ th of a cubic inch !* The vegetable kingdom presents us with innumerable instances, not only of the extraordinary divisibility of matter, but of its activity, in the almost incredibly rapid developement of cellular structure in certain plants. Thus the *Bovista giganteum* (a species of fungus), has been known to acquire the size of a gourd in one night. Now supposing, with Professor Lindley, that the cellules of this plant are not less than the $\frac{1}{100}$th of an inch in diameter, a plant of the above size will contain no less than 47,000,000,000 cellules; so that, supposing it to have grown in the course of twelve hours, its cellules must have been developed at the rate of nearly 4,000,000,000 per hour, or of more than sixty-six millions in a minute !† and when we consider that every one of these cellules must be composed of innumerable molecules, each one of which is again composed of others, we are perfectly overwhelmed with the minuteness and number of the parts employed in this single production of nature. But the animal kingdom perhaps presents us with still more striking instances than these. Thus animalcules have been discovered whose magnitude is such that a million of them does not exceed a grain of sand; and yet each of these creatures is composed of members as curiously organized as those of the largest species; they have life and spontaneous motion, and are endowed with feeling and instinct. In the liquids in which they live they are observed to move with astonishing speed and activity, nor are their motions blind and fortuitous, but evidently governed by choice and directed to an end. They use food and drink, from which they

* System of Inorganic Chemistry, I. 7.
† Introduction to Botany page 7.

derive nutrition, and are therefore provided with a digestive apparatus. They have great muscular power, and are provided with limbs and muscles of strength and flexibility. They are susceptible of the same appetites and obnoxious to the same passions. Must we not conclude that these creatures have hearts, arteries, veins, muscles, sinews, tendons, nerves, circulating fluids, and all the concomitant apparatus of a living organized body? and if so, how inconceivably minute must these parts be? If a globule of their blood bears the same proportion to their whole bulk, as a globule of our blood bears to our magnitude, what power of calculation can give an adequate notion of its minuteness?*

We have thus endeavoured to convey some idea of the magnitude of the ultimate molecules of which bodies are composed; but though we have succeeded in showing that they cannot exceed a certain magnitude, we are by no means certain that they are not in reality much less—indeed a great deal less than the least magnitude of which we have endeavoured above to convey a conception: yet notwithstanding this inapproachable minuteness, they retain all the characters of matter in the highest degree, and moreover possess certain remarkable properties in common, upon the nature of which, in the next place, we have to make a few remarks.

Section II.

Of the Forms of Aggregation of the ultimate Molecules of Matter.

Matter in the aggregate, and as it appears to exist in the world around us, is known to us principally in three forms or conditions:—the *Solid*, the *Liquid*, and the *Gaseous* (the latter including the state of vapour and the etheriform condition of matter); these in their well marked states are sufficiently distinct, though the whole gradually run into each other; the solid into the liquid, and the liquid into the gaseous, by such imperceptible grades, that in many instances it is not easy to say where one ends and the other begins.† The notions, which the mechanician or natural philosopher employs in reasoning on these forms of bodies are—of a solid, that all its parts are indissolubly and

* Lardner's Cyclopedia, Art. Mechanics, p. 13.

† It may be proper here to observe that some bodies, as water, for instance, are capable of existing in that perfectly gaseous form denominated *vapour*, under all ordinary circumstances; thus even ice gives off vapour rapidly, as we shall find hereafter.

unalterably connected, and impenetrable, so that the relative situation of the parts among one another, cannot be changed, or one part be set in motion without all the rest; of a liquid, that all its parts are freely moveable among one another, but that it is not dilatable or compressible by mechanical means; of a gas or aeriform body, that all its parts are not only freely moveable among one another, but that it is compressible and dilatable without limits. Strictly speaking, however, there are no objects in nature actually existing which completely conform to these definitions: no solid, for instance, absolutely hard and impenetrable, no fluid not compressible and dilatable, no gas compressible or dilatable without limits: and these circumstances are evidently the natural result of their being composed of aggregations of the minute molecules we have been considering. Thus solids composed of such molecules must necessarily have innumerable interstices or pores; hence, when submitted to pressure, they are liable to undergo more or less of condensation, and apparently occupy less space than before: the same remarks may be made with respect to liquids; while gaseous bodies, supposed to be composed of such molecules, of course cannot be infinitely compressible.

Section III.

Of the solid Form of Bodies. Crystallization.

Natural solids present us with a variety of properties usually termed *secondary*, many of which are of the utmost importance: such are *hardness* and *softness*, *elasticity*, *toughness*, *malleability*, *tenacity*, *ductility*, &c., all too well understood to require definition here. These properties evidently depend in a great degree upon original differences in the properties of the component molecules themselves; but there is no doubt that many of them are also intimately connected with the modes in which the molecules are arranged. Of these modes we can form no precise idea in a great many instances: there is, however, *one* form of solid aggregation, the *regular crystalline form*, which has occupied much more attention than the rest, and upon this we shall proceed to offer a few remarks.

As an object of illustration we shall select the familiar one of *water*, which from its well known properties of existing either as a solid, a liquid, a vapour, or a gas, by a slight variation of circumstances, is well adapted for our purpose, as we are thus enabled to employ the same object of illustration throughout. At present we have to consider it in its solid form of *ice*.

Every one must have remarked that water in the act of freezing assumes various symmetrical forms, shooting into speculæ, &c., as may be beautifully seen on our windows on a frosty morning. Now this affords a familiar instance of what is termed *crystallization*, a property apparently possessed by all ponderable matter, and readily exhibited by it when under favourable circumstances: and it has been remarked that the form assumed by the same matter is usually similar, or easily deducible from some common form according to well-ascertained and obvious laws. Let us now briefly inquire into the properties which the ultimate molecules of water must be supposed to possess to enable them to form these symmetrical aggregations. In the first place it is evident that the simple supposition of mutually attractive forces between these molecules, analogous or identical with the forces of gravitation, is inadequate to explain the phenomena. Possessed of such properties alone the ultimate molecules of bodies might indeed be imagined to adhere together, and their aggregations might even exhibit something like regularity, but this regularity would in a great measure be accidental, and probably never twice alike; hence the utmost latitude of assumption would never enable us to explain upon such principles alone that sameness of figure above alluded to as always assumed by the same matter. It is obvious, therefore, that the ultimate molecules of bodies are influenced by other powers than those of simple *inertia* and attraction: what is the nature of these powers? On this point there have been various opinions. Some have supposed the ultimate particles of bodies to possess shapes identical with those of the aggregates which they form; that a crystal, for example, whose shape is a cube, is formed by the aggregation of a number of infinitely little cubes, &c. But to others this supposition has appeared so improbable, and so unlike the usual simplicity of nature's operations, that they have rejected it, and have formed the more feasible hypothesis, that the ultimate molecules of bodies are either spheres, or spheroidal, that is to say, more or less, *virtually* globular.* Let us take it for granted then that the ultimate

* Strictly speaking, perhaps this observation is applicable to the forms supposed to be assumed by the influences surrounding the molecules, and by which all their operations are directed, rather than to the absolute forms of the molecules themselves, which, though in all instances virtually exerting spheroidal influences, must, in different instances, have very different forms. Those who wish to study the principles upon which spheroidal molecules may be supposed to aggregate into crystalline forms, are referred to Dr. Wollaston's interesting paper on the subject in the Philos. Trans. 1813, p. 51. It may be noticed, however, that the principles here advanced differ materially in other respects from those referred to.

molecules of bodies are spheres, with what powers is it necessary to suppose these little spheres to be invested in order to enable them to cohere and form the symmetrical figures we observe among natural bodies? The existence of simple, mutual and general attractive powers among such a set of molecules, has been already observed to be inadequate to explain the phenomena; there must be some specific powers determining similar particles, to combine in similar ways, otherwise the same resulting forms could not be supposed to take place. In the three small spheres,* (Fig. 1.) let us suppose the points *Ee*, *Ee*, *Ee*, on their superficies to be endowed with the following properties, viz. that the similar points, *E*, *E*, *E*, and *e*, *e*, *e*, have the property of mutually repelling each other, while the dissimilar *Ee*, *Ee*, *Ee*, have the property of mutual attraction. In such a case the three molecules will readily combine *E* to *e*, as in Fig. 2, but in no other way. Now let us suppose the same three spheres to be endowed with properties at the points *Mm*, *Mm*, *Mm*, as in Fig. 3, very similar to those at *E e*. Spheres so endowed will aggregate readily, as in Fig. 4, *E* to *e* and *M* to *m*, but in no other way; and thus instead of a single line we obtain a plate of molecules one in thickness.† To form the third dimension, or to constitute a solid, it is necessary to assume the molecules as in fig. 5, to be possessed not only of the attractive points *E e*, *E e*, *E e*,

Fig. 1.

Fig. 2.

Fig. 3.

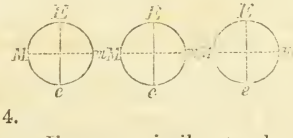


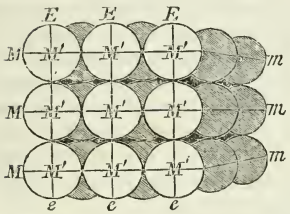
Fig. 4.

* Or rather sections of spheres, and the same is to be understood of all the subsequent figures.

† Here it is to be observed that the similar poles *E E*, *e e*, of each pair of molecules being supposed to be repellent within certain limits, as will hereafter be explained, their absolute contact is prevented, and the two molecules are balanced, as it were, between the two opposing and the two attracting forces. The consideration of forces operating in these and in the other modes, subsequently mentioned, present some highly interesting and novel objects of research for the mathematician.

Fig. 5.

Fig. 6.



Mm, *Mm*, *Mm*, but also of *M' m'*, *M' m'*, *M' m'*, (the point *m'*, being supposed to be opposite to the point *M'*, and out of sight.) Molecules so endowed will readily combine as in Fig. 6, and form a cube or some figure obviously deducible from it, but in no other manner; and in this way by assuming certain attractive and repulsive points upon our spheres at appropriate parts of their superficies, it is not difficult to conceive them capable, in different instances, of forming aggregates of any shape whatever. The next point to be considered is, how far are we authorized in making such apparently complicated and gratuitous assumptions respecting the properties of the ultimate molecules of matter; are there any phenomena in nature justifying such conclusions, and what are they? And this leads us to inquire further, but as briefly as possible, into the phenomena of aggregation, as we see them constantly going on around us.

Aggregation is usually considered as of two distinct kinds, viz. that depending upon the simple cohesion of *similar* molecules of matter, as of water, and which for the present may be supposed to undergo no change by the combination; and that depending upon the union of *dissimilar* molecules of matter, capable of exerting a mutual *chemical* change upon each other, in which case the aggregate is a *tertium quid*, or third something differing altogether from either of the original molecules composing it. Now both these kinds of aggregation obviously exist in the same substance, at least when in the solid form. In the first place the chemical aggregation is exerted between the heterogeneous molecules, (hydrogen and oxygen in the present case of water) which uniting, form compound homogeneous molecules, (of water); while in the next place, the molecules of water uniting *chemically* in one direction and *cohesively* in the other, form the solid crystal (of ice). Hence chemical aggregation and cohesive aggregation are as distinct as the polarities themselves upon which they depend; and if the one existed alone without the other, no such thing as a regular crystalline solid would probably be formed in nature.

From the above views, of molecular forces, it follows as a consequence that every molecule, and crystalline aggregate of

molecules, must possess one axis (as that, for instance, joining the polarities *E e* in the preceding figures,) having totally different powers and properties from the other two axes and polarities. This axis, by way of distinction, may be called the *chemical* axis and polarities. The other two axes (and indeed every other axis that can be supposed to be drawn, through the centre, from opposite points of the superficies of the molecule) probably possess common properties, and may be called the *cohesive* axes and polarities. Here then the existence of two forces is indicated,—the one axial, the other equatorial, if we may be allowed the expressions. The next question is, do such forces actually exist in nature on the large scale, and what are these forces? Now late observations have proved, beyond a doubt, that the *electric* and *magnetic* are such forces. We proceed, therefore, to take a short view of electricity and magnetism.*

Electricity.—It would be foreign to our present purpose to enter into details respecting this or any other department of science we may have occasion to allude to: hence we shall content ourselves with a short summary of its general principles. It seems to be satisfactorily proved that the phenomena of electricity depend upon two energies, usually existing throughout nature in a state of equilibrium, in which state their peculiar powers are not perceptible; that this equilibrium is capable of being destroyed by a variety of causes, as friction, &c.; and that owing to the different capacities possessed by different bodies, for conducting and retaining them, these energies can be partially separated and kept asunder, in which state they are capable of exhibiting their peculiar powers. These powers are such, that if two bodies charged in excess with the same energy be brought into the vicinity of each other, they mutually repel each other; while two bodies charged with the two different energies mutually attract each other. In this disturbance of the equilibrium of the two energies, it is to be remarked, that in no instance do we suppose that the two energies are, or can be, entirely separated, so as to reside each, *per se*, in different bodies; but that a portion of the energy of the one body goes to the other body, which at the same

* It may be remarked, that as all parts of the superficies of our molecules, except the *chemical* poles, are supposed to be more or less capable of cohesion, their aggregation in the form of common crystallized solids may be readily conceived. With respect to the cohesion (if we may be allowed the expression) of the different chemical poles *E e*, of similar molecules with each other, such cohesion seems to be proved by several circumstances, which it would be foreign to our purpose at present to inquire into; but of which, perhaps, the optical properties of crystals will hereafter form one of the most striking illustrations.

time returns a corresponding portion of its antagonist energy; hence, other things being equal, each body contains the same total quantity of the two electricities as before the equilibrium was destroyed. For the sake of the general reader, the matter, in short, may be represented numerically as follows:—Let us suppose that 2000 balls, all exactly of the same size, &c., but one half black and the other half white, are divided into two equal groups, A and B, of 1000 balls each, but in such a way that the group A shall contain 200 black and 800 white balls, and the group B 800 black and 200 white balls. In this case the two groups will correspond exactly with two bodies in different states of electricity; and (supposing them to be possessed of similar powers), if a third group, C, containing 200 black and 800 white balls be brought into the neighbourhood of the group A, which is similarly constituted, the two will be found mutually to repel each other, till they approach within a certain distance, that is to say, till the 200 black balls of each group come into action, and unite each with 200 white balls. At this distance they will no longer repel but attract each other; although, instead of forming a state of equilibrium, the white balls (or one of the electric energies,) will predominate. The same thing precisely may be supposed to happen if a fourth group, D, composed of 800 black and 200 white balls, be brought into the neighbourhood of the group B. But if the group A, containing 200 black and 800 white be brought into the neighbourhood of the group B, containing 800 black and 200 white, the two will attract each other, and combine to form the original group of 2000 balls, consisting of 1000 of each kind, as at first supposed.

Such are, we believe, the fundamental laws of action and equilibrium of the two electric energies. There is one circumstance immediately arising out of them, which, as it is the most frequent and important of all the causes disturbing the natural equilibrium of the two energies in different bodies, we shall briefly explain: we allude to what are usually called the phenomena of *induction*. Suppose an electrified body A, (that is to say, a body having the equilibrium of its electric energies destroyed, as above mentioned,) be brought into the neighbourhood of another body, B, in its natural state, what takes place? The electricity E, of the body A, acting upon the corresponding electricity E, in the body B, repels it to the furthest extremity of the body B; and at the same time attracts to that end of the body B which is nearest to the body A, the other and opposite electricity *e*. The body B, therefore, while under the influence of the body A, will exhibit all the phenomena of electricity, and is said to be *electrified by induction;* but remove this body B from the neighbourhood of the body A, and immediately the natural equilibrium of the energies

of the body B will be restored, and all signs of electricity will vanish. In this experiment neither of the bodies gains or loses anything. As these phenomena are constantly occurring in nature, and as we shall have frequent occasion to use the term *induction*, we have endeavoured to convey an idea of the nature of the subject to the general reader.

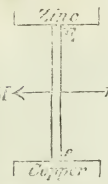
Of Galvanism.—While we are upon the subject of electricity, we may briefly notice that important modification of it termed *galvanism*. This form of electricity, instead of being evolved by friction, is usually obtained by the mutual action of various metals and chemical agents upon each other. Late experiments, however, have shown that the energies thus developed, differ in no respect from those of common electricity, but that they are obtained in this way in much greater *quantity* only, though in a lower state of *intensity* than by the common machine; and that many of the supposed peculiar effects of galvanism are the consequence of the *motion* of such large quantities of these energies, through bodies of various conducting powers. Galvanism has recently attracted much more attention than ordinary electricity, from the facility with which it may be applied to the purposes of the chemist, and from the extraordinary light it has thrown upon many chemical phenomena. Indeed, the chemist has been more indebted to the energies of galvanism than to any other; and he will probably be still further indebted to them than he yet has been. With respect to the phenomena of galvanism, these in most respects, so closely resemble the phenomena of electricity, that they do not require further illustration here.

Of Magnetism.—The general phenomena and laws of magnetism are very analogous to those of electricity. There are evidently two antagonist energies, which, while in a state of equilibrium, are not cognizable; but when separated, each one is mutually repellant of its similar, and mutually attractive of its opposite or antagonist. Thus the two north or two south poles of two magnetic needles mutually repel each other (with the same exceptions as the two electric poles), but the north pole of one needle and the south pole of another, mutually attract each other. Bodies are also rendered magnetic by induction when in the vicinity of another magnet, precisely as happens with respect to electricity. Magnetism principally differs from electricity in being apparently limited to a few bodies, as iron, and two or three others; but late observations have thrown an entirely new light on this part of the subject, which we have next to consider. Before we proceed, however, we may make a few remarks upon the obvious questions:—What becomes of the two electric and two magnetic energies when in a state of equilibrium? Do the electric and

magnetic energies combine to yield the same, or a different result, and what is the nature of this result or results, and in what form do they exist around us? On these points different opinions have been held: some supposing that by their union, both the electric and the magnetic energies alike constitute *heat;* others something else. That both are most intimately connected with heat and light, is evident; but at present we decline to give a decided opinion on the subject.

We come now to consider the relations of electricity and of magnetism to one another—a discovery which we owe to Oersted, and one of the most important that has been made in the present age. The following is a summary of these relations. Let us suppose, in the annexed figure, *E e*, to represent the wire connecting the zinc and the copper terminating plates of a galvanic battery in action. From what has been said, it may be conceived that under these circumstances there will be two currents *moving* through this wire in opposite directions; (from the copper to the zinc, usually called *positive* electricity, which may be supposed to be represented by our black balls in the previous illustration; and from the zinc to the copper, usually termed *negative* electricity, which may be represented by our white balls). Now in this state of things it has been satisfactorily established by experiment, that besides these two currents, there are two others having totally different properties, indeed all the properties of the magnetic energies, *moving*, not in the direction of the wire, but *in circles, or rather spirals, round it.* The energy corresponding to the north pole of the magnetic needle moves from right to left, round the wire, as above posited, while the energy corresponding to the south pole of the magnet moves in the opposite direction, or from left to right. Hence when a delicate magnetic needle *M m*, is placed *above* the wire *E e*, its north pole *M*, will be attracted by the current moving from left to right, with which it comes first in contact; and its south pole, for similar reasons, will be attracted by the opposite current. A needle so placed will consequently assume the direction represented in the figure, with its north pole *M* to the left; and if it be carried round the wire by its point of suspension, it will be always found to keep the same relative position with respect to the wire. Thus when *below* the wire, the needle will apparently point in the opposite direction; when on the same level, on the *left* hand, vertically downwards; when on the *right*, upwards.

Fig. 7.



Bearing in mind these relative positions of the currents and

needles, in what follows we may neglect the currents and judge from the position of the needles alone. Let us consider the case of two connecting wires placed by the side of each other, as in the figures annexed, and which wires may be supposed to repre-

Fig. 8.

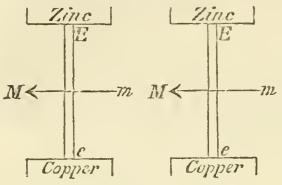
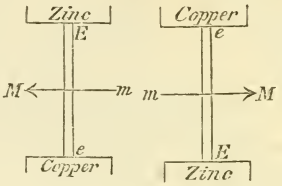


Fig. 9.



sent the chemical axis of our molecules. Now these wires, in consequence of the magnetic energies circulating round them, will mutually attract or repel each other, according to their position. If as in fig. 8, they are both in the same relative position, they will mutually attract each other, as may be inferred from the position of the needles, *Mm*, *Mm*, the north pole of one of which corresponds with the south pole of the other; but if one of the wires be reversed, as in fig. 9, they will mutually repel each other, the two similar poles of the needles in this case being contiguous. These relations hold universally, and what is most important, recent observations have shown them to be reciprocal; that is to say, if the magnetic energies be made to move in straight lines, the galvanic energies are found to circulate round them precisely in the way, and according to the laws above described as happening to magnetism round electricity. Hence electric sparks, and indeed all the phenomena of electricity can now be obtained from a common magnet.

Whether electricity and magnetism be different forms of the same energies resulting from the different directions of their motions—whether they be distinct energies—whether they be the cause or the effect of *Polarity*, we shall not stay to inquire; it is sufficient for our present purpose to know that they are inseparably associated with one another in the manner stated, and are always present at least in, if they be not the immediate cause of, all molecular actions among ponderable bodies. And this brings us back to the point, where we digressed to consider the subjects of electricity and magnetism.

We attempted to show that the ultimate molecules of matter must possess two kinds of Polarity; one which we have denominated *Chemical* Polarity, of a binary character, and existing

between molecule and molecule, chiefly when of *different* kinds; and another denominated *cohesive* polarity, determining, under certain circumstances, molecules of the *same* matter to cohere. We further attempted to explain how these polarities (each supposed to be connected by its own proper axis) must exist or be distributed in our molecules so as to fulfil the offices assigned to them, and which they evidently fulfil in nature. Lastly, we have shown that the electric and magnetic polarities or energies are actually related to one another, precisely in the same way that we supposed the chemical and cohesive polarities to be. The question then at once arises,—are these forces identical? Do the electric polarities correspond with the supposed chemical polarities, and the magnetic with the cohesive polarities of our molecule?

To us, we have no hesitation in saying, this conclusion seems very probable, nay, almost inevitable, not only for the reasons stated, but for others equally striking, that we shall have occasion to refer to hereafter. In the mean time we may briefly consider the subject with a little more attention, and principally with reference to some apparent objections that may be raised against it. In the first place it may be objected that it is difficult, from what we know of the varying and capricious character of the electric energies, to suppose that they can ever exist in that definite and permanent form in which they must exist if they be really identical with the cause of chemical affinity. To this objection, it may be replied, that magnetism can and does exist permanently in bodies for ages, and as electricity is an inseparable attendant upon magnetism, this energy must also have equal permanence. Again, a portion of zinc and a portion of copper placed in contact produce electrical effects as constant and enduring as the metals themselves. The argument, therefore, founded upon the want of permanence, and uniformity of the electric and magnetic energies, cannot, if duly considered, be supposed to have any weight; for the molecule may be conceived to be composed of two parts analogous to the copper and zinc in contact, and the electricity and accompanying magnetism evolved may be supposed to be as permanent in their character as the parts of the molecule evolving them. To the argument that electricity and magnetism, as we are acquainted with these energies, are *inadequate* to produce the effects and explain the phenomena of chemical affinity and cohesion, it may be replied, that they may be so: but that these energies, as we are acquainted with them, are probably merely accidental and peculiar modifications of the real energies, which in their elementary form, may be something altogether different, and quite unknown to us. In proof of this no-

tion, it may be observed, that the electricities of the common machine and of the galvanic machine apparently differ materially; while that existing in certain animals appears to differ from both. The magnetism evolved by electricity differs also slightly from common magnetism, yet no one now doubts that these differences arise from varieties in the quantity and intensity of the same energies, which in their elementary form, therefore, may, and probably do, differ from all these varieties. At any rate, we are unable to say that one of these varieties is more elementary than another, and consequently we have no right to assume that either of them is elementary, much less to found any argument upon the assumption.

Before we quit this subject of polarities and polarizing forces, it may not be amiss, in the last place, to make a few general remarks on the points in which they resemble or differ from those of gravitation.

The forces of gravitation, *inertia* and attraction, appear to be associated, and to reside in every individual *atom* of matter in the universe; hence every atom mutually attracts and is attracted by every other atom. The polarizing forces, on the other hand, are evidently disassociated, and reside in different parts of the same *mass;* hence this mass can in no instance be a mathematical point, (or atom?), but must consist of at least two parts; hence, also, as all matter appears to possess polarity, matter must exist in the state of mass or *molecule*, each of which molecules must occupy actual space. Thus the forces of gravitation and those of polarization are quite distinct. The forces of gravitation are primordial, and probably co-existent with matter; while the forces of polarization have more of a derivative or resultant character, and are evidently subordinate to those of gravitation. The question here naturally arises,—Are these different forces related to one another? Do the forces of polarization consist of the forces of gravitation in a state of separation, (if we may be allowed the expression,) or do they result from the motion of the molecules upon their axes? These are questions quite beyond our powers,—indeed we have nothing to do with them,—our present object being merely to point out the apparent limits within which the Deity has chosen to confine his operations.

Section IV.

Of the Liquid Form of Bodies. Of Heat.

Hitherto we have spoken of the aggregation of molecules in the solid form only; we have next to consider their arrangement

in that state in which they constitute a liquid. Our notion of a fluid, generally speaking, is, that all its parts or molecules, instead of being fixed, are perfectly moveable among one another; our notion of a liquid (the least perfect form of fluidity) is, that its molecules are incompressible. Now, still retaining water as our example of a liquid, let us consider what must happen to its molecules situated, as we suppose them to be, in the form of ice, before they can be so arranged as to constitute the liquid water. A moment's reflection teaches us that they must be loosened or separated from each other; and, as they cannot separate themselves, that some new agency is requisite for this purpose. It need scarcely be mentioned that this agent is *heat;* on the general phenomena and laws of which most important principle we now proceed to make a few remarks.

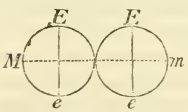
The sensations termed *heat* and *cold* are too well known to require explanation. These sensations, however, like all others, are merely the effects of some external cause or causes, operating on and through our organs, in a manner totally unknown to us. Various opinions have been entertained on the subject; some considering the cause of heat (caloric) to be an existent and material fluid, though of such extreme tenuity and imponderability as to escape our observation, and to become manifest to us only by its effects upon our sensations, and upon all the ponderable forms of matter; others considering it not as material, but as a property or principle of motion, which by exciting a certain species of vibration among the particles of bodies causes the sensations and effects of heat. Such are the most usual opinions, and the probability is, that they are neither of them literally correct, but that heat, and we may add light, are substances, the molecules of which are influenced by polarizing forces precisely similar in all respects to those which influence common matter; that is to say, that the molecules of heat and of light obey laws, similar in all respects to those which govern the molecules of ponderable bodies.* We have already alluded to the opinion maintained by some, that heat is a compound principle (like water for instance), consisting of a union of the two forms of electricity. We now draw the attention of the reader to this hypothesis, in order to state, that whatever heat may consist of besides, it is almost impossible to explain its

* We are aware that this opinion is opposed to that of most mathematicians, who favour the undulatory theory of light, and with good reason, so far as they have occasion to consider it; but we are decidedly of opinion that the *chemical* action of light can be explained only upon chemical principles, whatever these may be. Whether these chemical principles will hereafter explain what is now so happily illustrated by undulæ, time must determine.

effects upon the polarizing forces, without supposing that it at least involves, if it do not pass into the electric forces, upon which the polarizing forces *appear* to us to depend. We have said *appear*, for as has been already stated, though it is convenient to consider the polarizing forces under the forms of electricity and magnetism, in which they are most usually and palpably manifested to us among ponderable bodies, yet, in their elementary form these forces may in reality be something very different, not only from those of electricity and magnetism, but from all others with which we are acquainted ; while electricity and magnetism, themselves, may be nothing more than the effects of these elementary forces upon the subtle matters of which the electric and magnetic molecules are composed.

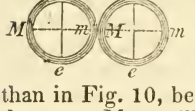
One of the most general effects of heat is the increase of volume which it produces in all bodies in which it is accumulated. There are a few exceptions to this law, and one of so curious and important a character as to require especial notice hereafter. In the mean time, however, the generality of the law may be taken for granted, and an attentive comparison of what has preceded and follows, will perhaps throw some light upon the nature of this phenomenon.

Fig 10.



Let us suppose Fig. 10, to represent, as in our former illustrations, two molecules of ice, with the chemical axes *E e*, *E e*, parallel and similar. In this state their cohesive polarities will be dissimilar, and the molecules, of course, will cohere as represented. Let us now suppose, from some external source, a certain quantity of heat to be communicated to these molecules. The natural tendency of heat is usually considered to be to arrange itself in the form of an atmosphere, around the molecules as in Fig. 11 ; the consequence of which is, that their apparent temperature is raised a certain quantity, and they will be separated from each other in some slight degree ; they will thus occupy more space than in Fig. 10, before the addition of heat ; the cohesion between the parts *M m* will also at the same time be diminished. And here it may be proper to notice an important fact, that the same quantity of heat when introduced into different bodies produces very different *apparent* temperatures and effects, and that this constitutes what is called by chemists their *capacity for heat*, or their *specific heat*. Thus if the same quantity of heat, which we supposed to have been introduced into two molecules of ice, had been introduced into two molecules of silver, their apparent temperature would have been raised more than ten times as much as that of

Fig. 11.



the molecules of ice ; hence in the case of the ice some of the heat must have disappeared, or become, in the language of chemists, *latent*, a most important property of heat which we have next briefly to inquire into. Previously, however, it may not be amiss to observe, that the molecules of heat are supposed to be vastly less than those of any ponderable substance ; and that they may thus, without any incongruity, be supposed capable of forming an atmosphere around the ponderable molecules, which they could not otherwise of course be imagined to do.

The *latency* of heat appears to depend upon two totally different phenomena, or rather, properly speaking, is of two distinct kinds, as may be thus illustrated. Let us take the two bodies above alluded to—ice and silver ; these under the same volume contain very unequal portions of matter, the silver being ten times as heavy as the ice. The vacuities in the ice, therefore, must be very much greater than those in the silver; hence, when the same quantity of any principle, capable of occupying such vacuities, as heat may be supposed to be, is introduced equally into both, very dissimilar apparent effects must be produced. The more porous body will absorb and condense within its vacuities the added principle, and leave but little external and sensible ; while the less porous body, having less room among its pores, will exhibit a larger quantity external and sensible. The more porous body, therefore, may be said to have a greater capacity for heat than the less porous body, from its greater power of absorbing heat, and rendering it latent.* This, we believe, is the usual explanation of the phenomenon under the assumed circumstances, and it is probably correct to a certain extent: but there is obviously another form of latent heat, totally different from the above, and which evidently cannot be explained on the same principles, and this we have now to consider. Let us suppose that into a mass of ice, cooled considerably below the freezing point, a uniform and regular flow of heat be determined from some external source ; the temperature of the ice, of course, will gradually go on increasing till it rise up to the freezing point; it will then suddenly stop, and remain stationary till a quantity of heat, equal to 140 degrees of the thermometer, have flowed into the ice. The ice has now become water ; but up to that point the water still retains the original temperature of the ice ; after that point, however, if the heat continue

* This union of heat with ponderable bodies may, perhaps, be considered as analogous to the condensation of gaseous bodies by porous substances—a very remarkable set of phenomena, which deserve to be much more carefully studied than they have been. The absorption of light is probably of a similar nature ; and the whole apparently depend upon chemical principles, and probably, if studied in connexion, would mutually illustrate each other.

to be applied, the water acquires apparent temperature as before. Now in this experiment a quantity of heat equal to 140 degrees of the thermometer has actually disappeared; but this disappearance cannot be explained in the same manner as that above mentioned; for the water, instead of being greater in volume, and consequently having greater vacuities than the ice from which it was formed, is actually less, and must therefore contain fewer vacuities. How then are the phenomena to be explained? We commenced our observations upon heat, by alluding to the hypothesis that this principle is capable of being decomposed into two energies, if not identical with, at least operating in the same way as those of electricity. In the above experiment, therefore, we consider that the 140 degrees of heat which have disappeared, are decomposed and converted into the two polarizing energies; and that these energies thus produced are superadded to the energies already existing attached to the molecules of water, and in this way increase their total quantity or intensity. The changes induced in the relative position of the molecules of water, by this increase of intensity in their energies, may be illustrated as follows:—Let Fig. 12, as before, represent the position of two molecules in the state of ice. Here the similar poles $E\ E$ and $e\ e$, are of course mutually repellent, while cohesion takes place between the dissimilar polarities, as shown in the figure. Now suppose the polarities, $E\ E$, $e\ e$, to be suddenly much increased in intensity, so as to extend beyond the semi-diameter of the spheres; they will of course repel each other, and in such a way that the two spheres will revolve on the common axis of adhesion $M\ m$, and the axes $E\ e$, $E\ e$, instead of remaining parallel, will become at right angles to each other, as in Fig. 13; or rather as in Fig. 14. In Fig. 14, a view is supposed in the direction of the common axes, $M\ m\ M\ m$, of Fig 13. in which view, of course, $E\ e$, $E\ e$, are supposed to represent the chemical axes of the two spheres at right angles to each other. Hence in the liquid state of bodies the position of the axes of adjoining molecules may be supposed to be at right angles, or in some position less than right angles and approaching parallelism. At exact right angles the cohesive polarities are balanced and neutralized, so that the points $M\ m$ have neither a tendency to unite nor to separate, but remain simply in contact. Hence the molecules of such a body will be all disassociated and free to move among one another; and if we suppose each molecule at the same time to be surrounded by its

Fig. 12.

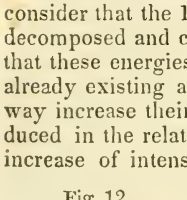


Fig. 13.

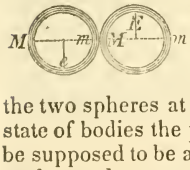
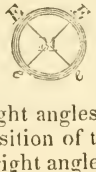


Fig. 14.



atmosphere of caloric, so thin as not altogether to remove mechanically the molecules beyond one another's influence, we have probably as clear an idea of the nature of a liquid as we are capable of forming.

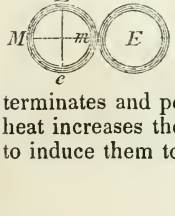
Section V.

Of the Third or Gaseous Form of Bodies.

We have next to consider the most perfect form of fluidity, that of gas, or (adhering to our former example), steam; and we shall, in the first place, take a short view of the molecular arrangement of bodies existing in the gaseous form, which will enable us still further to elucidate the subject of latent heat.

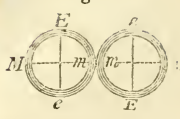
Let us suppose as before, the same constant stream of heat to be flowing into a portion of water that we supposed to be flowing into the ice: the water continues to increase in temperature and capacity for heat till it arrives at the boiling point; at this moment the temperature ceases to be augmented, however much we may urge the application of heat, and the water is converted into a transparent gas, well known by the name of steam; to effect this latter purpose, however, under the ordinary circumstances of atmospheric pressure, it has been found that nearly 1000 degrees of heat are necessary, which large quantity of heat actually becomes latent or disappears, since the temperature of the steam formed never exceeds 212°, that of the water at the boiling point. What becomes of these 1000 degrees of heat? We may suppose one portion of it to become latent in the first of the two ways described above; that is to say the water in the act of being converted into vapour, is much augmented in volume, and into this augmented volume, as into a sort of vacuum, a portion of the heat may be supposed to rush and become insensible; but another portion of heat is obviously decomposed, and goes to augment the molecular polarities of the water, which, in the case of steam (and in all gases), may be imagined to be arranged in some such way as the followlng:—

Fig. 15.



In Fig. 15, we have represented as before, though in a different manner, the chemical axes at right angles to each other; at which angle the cohesive polarities are balanced and neutralized. This angle, therefore, may be considered as the point at which liquidity terminates and perfect fluidity begins. The next augmentation of heat increases the chemical polaric intensities still further, so as to induce them to repel (or rather to attract) each other's axes into

Fig. 16.



the parallel position, Fig. 16; where the chemical polarities are quite reversed, and of course, the contiguous cohesive polarities *m* and *m* are brought into the maximum state of repulsion. Now such position, or some angle greater than a right angle, may be supposed to be that assumed by the chemical axes of the molecules of all bodies when in the gaseous state. Hence, as there are two kinds of attraction, so there must likewise be two kinds of repulsion, viz. heterogeneous or chemical repulsion; and homogeneous, or self-repulsion, opposed to cohesion, upon which the gaseous form of bodies principally depends.

But here a question arises: in what state are the molecules of bodies in the condition of vapour, as those of water at all temperatures below 212°; for instance at 32°? According to an hypothesis to be presently mentioned, a given volume of steam, at 212°, contains the same number of self-repulsive molecules as a similar volume of air under the same temperature and pressure, and therefore has the same elasticity. But the elasticity of the vapour of water at 32° is only equal to about 1-5th of an inch of mercury;* hence the same given volume of that vapour at 32° will only weigh about 1-150th of what steam ought to weigh, supposing it could exist as a permanent gas at 32°, and under a pressure of thirty inches of mercury. The molecules of the vapour, consequently, will be five or six times further apart than in perfectly gaseous bodies under a similar temperature and pressure.†

Let us now, in the last place, inquire how the above suppositions respecting gaseous bodies accord with their common leading properties, viz., with their self-repulsive or diffusive properties; their equable expansion by heat; their increase in volume in the inverse proportion of the force with which they are compressed; and with their similar capacities for heat.

* The elastic force of vapours increases with their temperatures; that is to say, according to our hypothesis, increases with the angle formed by the chemical axes of their molecules. At exact right angles the elastic force is 0; at 180° it is equal to that of air under similar pressure and temperature. Hence all intermediate elasticities lie between these two points.

† Supposing it were possible for steam to exist at 32°, of course at this temperature its weight would bear to that of air, the same proportion it bears at 212°, that is to say, as 5 to 8. Hence 100 cubic inches of steam at 32°, ought to weigh 20.49375 grains; or 5-8ths of 32-79 grains, which is the weight of 100 cubic inches of air at 32°. But the weight of 100 cubic inches of steam at 32° is only .1366 grain, or 1-150th that of air. The number of molecules in steam at 32° is consequently only 1-150th of those in air at 32°. Hence this diminution of the number of molecules, if we suppose them to be diffused equally throughout the same space of 100 cubic inches, must of course, as stated in the text, cause them to be between five and six times further apart.

Of the diffusion of Gaseous Bodies.—For the facts connected with this most important subject we are principally indebted to Dr. Dalton and to Mr. Graham; the latter of whom has shown that when any gas or air is confined in a vessel furnished with a very narrow aperture or with a porous plug, an interchange between the confined and the external airs immediately begins to take place through the communicating aperture; and that this interchange continues to go on to a certain point, which, with respect to the same gas, appears to be uniform, but differs in different gases according to a certain law. Two gases also, whatever may be their specific gravities, and however they may be introduced into the same vessel, speedily become mixed uniformly throughout. These facts evidently indicate a species of self-repulsive influence among the molecules of the *same* gas, which appears to be satisfactorily accounted for by our hypothesis. The argument is very simple and obvious: Two molecules of the *same* matter have a tendency to cohere and to form a solid, when the chemical polarities of these molecules are similarly arranged, and do not extend beyond the semi-diameters of the molecules; but two molecules of *different* matter, under circumstances precisely alike, remain passive, and have no tendency to cohere. Hence, while two molecules of the same matter, having the intensity of their polarities much increased, and their chemical poles, consequently, reversed, repel each other, or become *self*-repulsive; two molecules of different matter, still retaining their mutual passiveness, do *not* repel each other.

There is reason to believe that these phenomena are not confined to bodies perfectly gaseous, but exist also in that less perfect gaseous condition termed *vapour*, of which the vapour of water may be considered as the most familiar example. On this supposition, and particularly that the above law of diffusion holds among vapours, (which is probably the case, though in a modified form) the lower the specific gravity of the vapour, that is to say the lower the temperature, the greater the diffusive power; and consequently the more rapid the evaporation: a most important inference that will enable us to explain many meteorological phenomena at present quite inexplicable. Something very similar, if not identical with the above phenomena, also exists in liquids and perhaps in solids. Thus the molecules of certain matters diffused through a liquid, as water, may be supposed to exert in some cases a self-repulsive influence on each other, by which supposition only do their equal diffusion through a large mass of liquid seem explicable. Even in the solid state, as above observed, something of the kind appears to exist, especially among organized bodies, which apparently owe some of their most remarkable pro-

perties to the diffusion of active self-repulsive molecules throughout their substance.

Of the equal Expansion of Gaseous Bodies by Heat.—With respect to the second important property of gaseous bodies, that under the same temperature and pressure they all undergo equal expansion by an equal increase of heat; this seems to be explicable only on the supposition that *all gaseous bodies, under the same pressure and temperature, contain equal numbers of self-repulsive molecules:* a most important conclusion, as we shall see hereafter, and one, which at present we are anxious a little further to illustrate. Supposing the fact to be, as it is, undeniable, that within the ordinary limits of experiment, all perfectly gaseous bodies expand equally by similar increments of heat, *if* different gases contain *unequal* numbers of self-repulsive molecules, those gases which contain the least number of molecules, must exert the greatest power, and consequently have the greatest disposition to expand; in other words, the expansive power of the molecules of a gas, must increase as their number diminishes; and not only so, but in order to produce the effect stated, the expansive power must increase, neither more nor less, but exactly as the number diminishes—a law which when applied to extreme cases becomes obviously absurd. Further it may be observed, in corroboration of the hypothesis advanced, that in the gaseous state the molecules of bodies may be considered as having undergone the utmost effects, that any increase of heat can produce upon them. All their interstitial vacuities may be supposed to be already saturated with it; while an atmosphere may be supposed to surround each molecule, keeping them individually at a considerable distance from each other: their polarities also may be supposed to have undergone their ultimate change, so that no more heat can be rendered latent by inducing further changes, except in degree, which degree may be supposed to be common to all gases. Hence every molecule of matter, when in the gaseous state, and subjected to similar pressure and temperature, may, without reference to its other properties, be supposed to be in circumstances exactly similar, and consequently liable to be affected in an exactly similar manner by all further increments of heat.

Of the inverse Relation of the Volume to the Compressive Force.—Nearly the same remarks apply to this law as to the preceding; for were the numbers of molecules in each gas supposed to be *unequal*, the diminution of volume under similar pressure ought to vary also, which is not the case, at least in the more perfect gaseous bodies, and neither this observation, nor those in the former paragraph apply to vapours.

Of the similar capacity of Gaseous Bodies for Heat.—The best experiments seem to show that under the same pressure the

same volumes of all gases have the same capacity for heat—a circumstance quite according with the other phenomena. Hence, for the above and other reasons which might be mentioned, we have been induced to adopt the hypothesis already stated, that, *under the same pressure and temperature, all bodies in a perfectly gaseous state contain equal numbers of self-repulsive molecules.**

Section VI.

Other Properties of Heat. Of Heat in Motion.

Heat appears to be in a constant state of motion and of interchange between different bodies, among which it finally settles into a state of equilibrium. If accumulated in any body, this accumulation cannot be preserved; but the excess will fly off in spite of all we can do to the contrary, and sooner or later the equilibrium will be restored. This motion of heat takes place in three ways, which a common fire-place very well illustrates. If, for instance, we place a thermometer directly before a fire, it soon begins to rise, indicating an increase of temperature. In this case the heat has made its way through the space between the fire and the thermometer, by the process termed *radiation*. If we place a second thermometer in contact with any part of the grate, and away from the direct influence of the fire, we shall find that this thermometer also denotes an increase of temperature; but here the heat must have travelled through the metal of the grate, by what is termed *conduction*. Lastly, a third thermometer placed in the chimney, away from the direct influence of the fire, will also indicate a considerable increase of temperature; in this case a portion of the air, passing through and near the fire, has become heated, and has *carried* up the chimney the temperature acquired from the fire. There is at present no single term in our language employed to denote this third mode of the propagation of heat; but we venture to propose for that purpose, the term *convection*,†

* It is proper to observe that these views were adopted by the author long before he was aware of the existence of the essays on the subject by Messrs. Avogadro, Ampere, and Dumas. Indeed he was unacquainted with those of Dumas, which most nearly resemble his own, till he saw them alluded to in Mr. Johnston's recent report on chemistry in the Transactions of the British Association. Mr. Donovan seems to consider the above hypothesis as untenable; but we think his arguments entirely inconclusive. See Giornale di Fisica, sec. II. tom. viii. p 1.; Annales de Chimie, tom. xc. p. 43; a Treatise on Chemistry, by Mr. Donovan, in Lardner's Cabinet Cyclopædia, p. 379; and the Introduction to Dumas's Traite de Chimie appliquée aux Arts, which excellent work the author had been prevented from perusing by the nature of the title.

† *Convectio*, a carrying or conveying.

which not only expresses the leading fact, but also accords very well with the two other terms. Each of these modes of the propagation of heat possesses certain peculiarities, on which we proceed to make a few remarks.

Radiation of Heat.—Heat radiates *in vacuo* in all directions equally, and with immeasurable velocity. Heat radiates also through all gaseous bodies, and more or less through transparent media. Radiation goes on at all temperatures; but the quantity of heat radiated in a given time bears some proportion to the excess of the temperature of the radiating body above that of the surrounding medium. Radiant heat is capable of being *reflected* like light, (to be presently noticed,) and, indeed, obeys altogether somewhat similar laws. Those surfaces, however, that reflect light most perfectly, are not equally adapted to the reflection of heat. Metals in general, and particularly when highly polished, are the best reflectors of heat, while glass, which reflects light most perfectly, reflects comparatively little heat; thus tin-plate reflects about eight times as much heat as a glass mirror. The radiation of heat is much influenced by the nature and state of the surfaces of bodies. Thus a surface coated with lamp-black radiates eight or nine times as much heat as a polished surface of tin or silver; and in general polished surfaces, particularly of metal, radiate much less than other surfaces. As might be expected, this difference of radiating power exerts great influence in the cooling of bodies; thus warm water retains its heat much longer in a bright tin vessel, than in the same vessel coated with linen, paint, or particularly lamp-black. Radiant heat is *absorbed* with different facilities by different surfaces. The absorbing power of surfaces seems, indeed, to vary directly as their radiating power, and inversely as their reflecting power. That is to say, surfaces receive heat by radiation nearly with the same degree of facility as they give it off; while those that reflect most, of course, must absorb least; a surface covered with lamp-black, for example, receives in a given time eight or nine times as much heat by radiation as a polished tin surface receives. From these remarks, it will be readily inferred, that the colours of bodies may have considerable influence in the radiation and absorption of heat; now this is found to be the case, and the darker the colour of a body, the more readily it gives off, and absorbs radiant heat. Radiant heat has the power of passing through transparent bodies, as glass. This power, however, varies according to the thickness of the glass, its relative position to the radiating body, and a variety of other circumstances not well understood; but generally speaking heat seems to obey laws, more or less, analogous to those of light under similar circumstances.

Conduction of Heat.—The conduction of heat is chiefly con-

fined to solid bodies; and as solids exist of every degree of consistency and density, from perfect fluidity up to perfect hardness, the conducting power varies in like manner. Hence the laws of conduction and those of radiation have a mutual dependance; and, in fact, the laws of conduction may be considered as only extreme cases of the laws of radiation. The conduction of heat through bodies seems to take place equally in all directions. In general the densest bodies, as metals, stones, hard woods, &c., have the greatest conducting power, though these differ exceedingly among one another. Porous bodies in general are bad conductors; and of such bodies charcoal may be considered as one of the worst conductors. Among substances employed as articles of dress, hare's fur and eider down are the worst conductors, and flax the best. The relative conducting powers of substances of this class seem to depend much upon the quantity of air enclosed within their interstices, and the power of attraction by which this air is retained or confined. The conducting power of liquids and of gases is very limited, though under certain circumstances they *appear* to possess this power in a high degree. But this power is only *apparent*, and heat is chiefly communicated through liquids, and also through gases by the third process above alluded to, viz. *convection*. By convection however, heat is only propagated in one direction, namely, *upwards;* hence almost any degree of heat may be applied to the upper surface of a liquid or gas without affecting the lower.

Such are the principal phenomena connected with the motion of heat; but before we proceed to speak of the sources of this wonderful agent, we have yet to consider another imponderable principle of the utmost importance, and intimately connected with heat; viz., *Light*.

Section VII.

Of Light.

The laws of the motion of light, of its reflection, refraction, polarization, &c., properly belong to another department; we shall, therefore, only briefly describe them here, and endeavour to point out the general connexion and analogy they bear to the phenomena of chemistry, and more especially to the phenomena of heat and electricity.

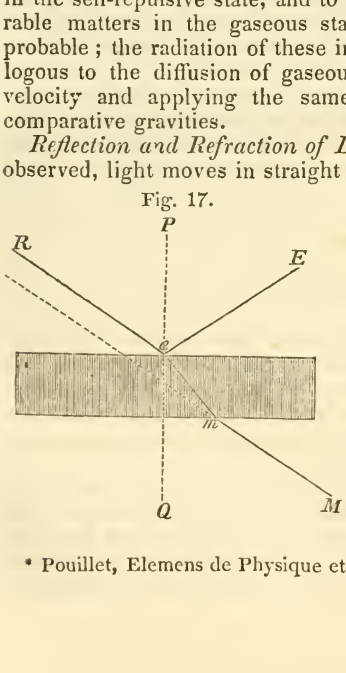
Radiation or Motion of Light.—Light radiates or moves in straight lines with such inconceivable velocity, that it occupies only about eight minutes in travelling from the sun to our earth, so that it must move at the rate of nearly 200,000 miles in a second! At the same rate it would occupy about four hours to travel to us

from the planet Uranus, the present *ultima Thule* of our system; hence if this planet were at any given instant suddenly annihilated, we should not miss it for four hours afterwards; and when we look at it, we do not see it where it actually is at this instant, but where it was four hours previously. A cannon ball, when first shot from the cannon, moves with a velocity of between 2000 and 3000 feet per second; supposing, therefore, it could retain its initial velocity, it would scarcely move in a year as much as light moves in a single second! The utmost velocities of the earth and other planets, in their orbits or on their axes, scarcely exceed 30 or 40 miles in a second. Hence the utmost velocity that we are acquainted with as possessed by ordinary matter, and therefore the utmost perhaps of which such matter is capable, only amounts to the 1-5000th or 1-6000th of that of light! These striking facts are mentioned with the view of conveying some notion of the immensity of space, and of the wonderful velocity with which it is in every direction penetrated by light. They seem also to show, that if light be matter, it must exist in a state of tenuity, totally different from the ponderable matter we are acquainted with, which actually seems incapable of such velocity.*

If we consider heat and light to consist of polarized molecules in the self-repulsive state, and to obey the same laws that ponderable matters in the gaseous state obey, which is exceedingly probable; the radiation of these imponderable bodies will be analogous to the diffusion of gaseous bodies, and by knowing their velocity and applying the same law, we may deduce their comparative gravities.

Reflection and Refraction of Light.—In free space, as before observed, light moves in straight lines; but when a ray, *R*, Fig. 17, falls upon a polished surface, as of glass, a portion of it is reflected in the direction *e E*, and the angle, *R e P*, called the angle of *incidence*, is always equal to the angle, *P e E*, called the angle of *reflection*. Another portion, *e m*, passes through the glass, but instead of continuing to move in the same straight line, is bent considerably out of that direction towards the perpendicular *P*

Fig. 17.

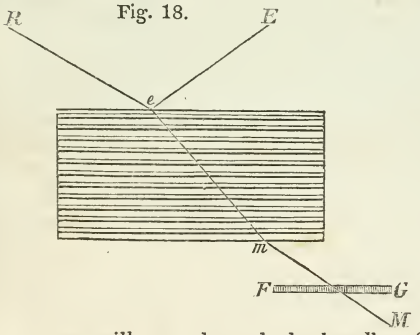


* Pouillet, Elemens de Physique et de Meteorologie tom. iii. p. 216.

Q; it then makes its exit at m, and goes on in the direction $m\ M$, parallel to its original direction, $R\ e$. This portion of the ray is said to have undergone *refraction;* a term indicating that its natural course has been broken. Such are the general facts; and the study of their laws, varieties, and peculiarities, as modified by different media, constitutes the science of optics, a branch of knowledge not falling within our present design. In connection with this part of our subject, it only remains to observe, that in passing through the most transparent bodies much light is lost, by absorption and in other ways. So also when light falls upon metallic bodies, such as polished silver, about one-half only is reflected, while the other half is absorbed and lost. Different substances, however, differ materially in these respects, and from the experiments of M. Bouguer and M. Lambert, it appears that in fluids, transparent solids and metals, the quantity of light reflected, *increases* with the angle of incidence reckoned from the perpendicular; whereas in white opaque bodies the quantity of light reflected, *decreases* with the angle of incidence.* We shall hereafter have occasion to revert to these curious facts.

Polarization of Light.—The next property we have to notice is what is called the *polarization* of light. Let us suppose Fig. 18, to represent a bundle of plates of thin window-glass, bound together in the manner indicated. Let $R\ e$ be a ray of light falling on the upper plate, at an angle of incidence of about 56°; a portion of the ray will be reflected, and will move in the direction $e\ E$, while another portion of the ray $e\ m$, will pass through the bundle of glass plates onwards to M, according to the laws of reflection and refraction already stated. Now these two rays $e\ E$ and $m\ M$, possess remarkable properties, similar to one another in most respects, but directly opposed in another. Of these properties we shall endeavour to give a general idea.

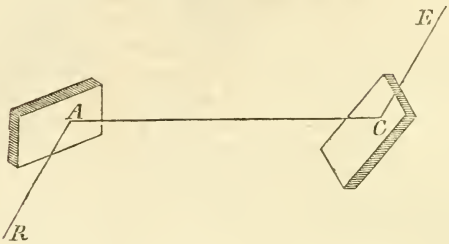
Fig. 18.



* See article Optics, p. 67, and 68, in the Library of Useful Knowledge. Where the original observations are to be found, which are there referred to, we do not at present know.

If the ray of light *R A*, after falling upon the vertical glass *A*, Fig. 19, at an angle of incidence of 56°, be received on a plate

Fig. 19.



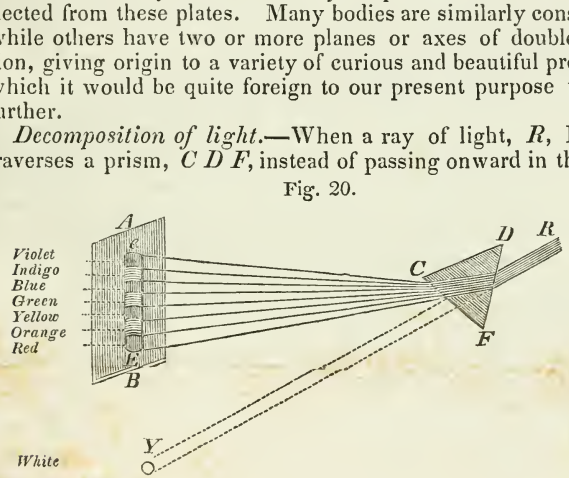
of glass, *C*, placed at the same angle of incidence, and be then reflected from *C* to *E*; in the position intended to be shown in the figure, when the ray *R* is first reflected in a horizontal plane, *R A C*, and then in a vertical plane, *A C E*, the ray *C E* becomes so weak as to be scarcely visible, the whole of it having passed through the glass *C*. But if the glass *C* be turned round 90°, (the ray *A C* being supposed to be the axis of motion) so that the ray *C E* be reflected horizontally; instead of passing through the glass *C* as before, the whole of the ray *C E* will be reflected. If we continue to turn the plate *C* upon the axis *A C*, round the entire circle, these alternations of transmission and reflection will be found to take place in the same manner at the two other quadrants 180° and 270°. Hence the ray *R A*, by reflection, has acquired properties altogether new; it is said in short, to have acquired *polarity*, or to have become *polarized*. Now recurring to Fig. 18, the ray *R e*, in that figure will of course follow the same laws as the ray *R A* in Fig. 19, that is to say, the ray *e E* will have acquired polarity by reflection. Let us now consider what has happened to the refracted ray *m M* in the same Fig. 18. This ray *m M* will also be found to be polarized; but if we receive it on a glass plate, *F G*, at the polarizing angle of 56°, we shall find that it will refuse to be reflected; whereas the reflected ray *e E* does not refuse to be again reflected, unless the plate *F G* be turned round 90°, or into a plane at right angles to that plane in which the refracted ray *m M* had refused to be reflected. Hence we conclude that when a ray of light is incident at the polarizing angle upon a transparent body, the whole of the reflected light is polarized; while the whole of the transmitted light is also polarized, but *in a plane at right angles* to that in which the reflected ray is polarized.

Such is the general law, and it may not be amiss to allude briefly to another familiar illustration of it. Every one is ac-

quainted with the mineral called Iceland spar, and with the singular property which this mineral possesses of forming a double image of objects seen through it, or its property of double refraction; that is to say when a ray of light falls on a crystal of such spar in a particular direction, the ray is separated into two. Now it is a remarkable fact that if these two rays be examined in the way before directed, when speaking of reflected and transmitted light, it will be found that both are polarized, but that the two rays are polarized in planes *at right angles to each other;* that is to say, the ordinary transmitted ray is polarized like the ordinary ray transmitted, through the bundle of glass plates; while the extraordinary transmitted ray is polarized like the ray reflected from these plates. Many bodies are similarly constituted; while others have two or more planes or axes of double refraction, giving origin to a variety of curious and beautiful properties, which it would be quite foreign to our present purpose to detail further.

Decomposition of light.—When a ray of light, *R*, Fig. 20, traverses a prism, *C D F*, instead of passing onward in the direc-

Fig. 20.



tion Y, it is refracted into the spectrum *E e;* which spectrum when received upon the screen, *A B*, will be found to consist of seven different colours, in the order and of the kind described, each having, of course, different refractive powers; the red being the least, and the violet the most refracted from the original direction *R Y*, of the solar beam. This oblong image is called the *solar*, or sometimes, the *prismatic spectrum*, and Sir Isaac Newton found that each colour consists of light no longer separable, like white light, into others, but having uniform refractive properties: hence he called all the seven colours simple or homogeneous, in opposition to white light, which he called compound or heterogeneous.* This important fact presents a clue to, and

* Sir David Brewster has lately shown that there are, in fact, but three simple colours, the *red*, the *yellow* and the *blue*, and that each of these

exhibits the general law which regulates the endless variety and change of colours; as bodies appear to have this or that colour, according as they have the power of reflecting or transmitting this or that colour, and of absorbing or reflecting the rest; while white bodies reflect all, and black absorb all. Besides colour, it has been likewise noticed that different portions of the prismatic spectrum possesses different *heating* and *chemical* or *electrical* properties. These vary in some respects, according to the nature of the prism employed. In general the heating power increases towards the red ray; while the chemical power seems to be regulated in some degree by the nature of the colour, but is greater (though of opposite character) at the two extremities than in the centre of the spectrum, where it appears to be nearly null. The chemical properties of light, however, are by no means well understood, and have not received the attention which they merit.

Upon an attentive consideration of the phenomena of heat and of light, and a careful comparison of them with the general phenomena of polarizing forces, it is impossible not to be struck with the close analogy that prevails throughout the whole. The phenomena of heat have hitherto been very imperfectly studied, and in consequence we are much less able to trace the analogy; but the phenomena of light from their obvious and striking characters have attracted more attention, are much better understood. To enter further upon the inquiry here would be quite foreign to the object of this treatise; we cannot however, in concluding these remarks, refrain from repeating an opinion already expressed, that the molecules both of heat and of light possess polarities precisely similar to those of ponderable bodies; and that not only the chemical agencies of these principles, but those phenomena of light also at present so beautifully illustrated by the hypothesis of undulæ, will be hereafter found to admit of explanation on the more probable supposition of molecular polarity.†

colours exists throughout the spectrum. Hence, probably, like the different electric and magnetic energies, these elementary colours, or, at least, the *red* and the *blue* (the *yellow* being probably merely resultant), can never be entirely separated from each other.

† In the Newtonian hypothesis of *fits of easy transmission and of easy reflection*, the molecules of light may be regarded as little magnets revolving rapidly round their centres while they advance in their course, and thus presenting alternately their attractive and repulsive poles. (See Discourse on the Study of Natural Philosophy, by Sir J. Herschel, p. 253.) In our hypothesis, the chemical poles of all self-repulsive molecules are supposed to be arranged positive and negative alternately; (see Fig. 16, page 54) by which arrangement the contiguous cohesive polarities are rendered of the *same* kind, and consequently repulsive. Hence when a series of self-repulsive molecules move onwards in virtue of their self-re-

Section VIII.

Of the Sources of Heat and Light.

The principal and obvious sources of heat and light are the sun, electricity, mechanical action; change of physical condition, change of chemical condition; and organic action.

The sun is the most obvious and unvarying source from which both heat and light are communicated to our earth. The nature of the sun, however, and the mode in which that wonderful supply of heat and light is maintained are quite unknown to us, and will probably always remain so. Electricity is another source of heat and light which are developed at the moment of the equilibrium of the two energies; and some of the most intense degrees of heat and light that have been produced have sprung from a galvanic apparatus. The sudden condensation of air is likewise a source from which heat and light are often both extricated, on principles that it will not perhaps be difficult to understand from what has been stated. The extrication of heat by percussion and condensation appear to be limited, but its extrication by friction seems to be boundless; that is to say, so long as friction is kept up, will heat continue to be extricated, but whence the heat is derived does not appear to be capable of satisfactory explanation, unless we suppose a perpetual decomposition and recomposition to take place, which is not improbable. Another fertile source from which heat is derived, is the physical change of condition which bodies are constantly undergoing in nature, as for example, the conversion of gases into liquids, of liquids into solids, &c. by taking advantage of which conversions we can accumulate heat at will, as for instance by the condensation of steam. When these physical changes however are associated with chemical changes, as is very often the case, the most striking effects are produced. Of this kind are all the phenomena of combustion,

pulsive powers, (as in the radiation of light, &c.) the cohesive axes of the molecules will always be in the line of motion, and each successive molecule will present alternately an opposite polarity; while the chemical axes of course will be all in the same plane, and transverse to the line of motion. Such will be the order in a single series of molecules in motion; but when a number of series move onward together, as in homogeneous light, there is reason to conclude that the molecules of contiguous series have a tendency to arrange themselves thus ·:·:·:·:· with the chemical axes at right angles to each other. Those who are interested in these subjects will perhaps readily conceive how such arrangements may be applied to explain the various phenomena we have been considering.

the most common source of artificial heat; and which consists of nothing more than the rapid chemical union of certain bodies with others, and generally with the principle termed *oxygen*. Nearly allied to chemical action, and perhaps identical with it, is the extrication of heat by organic changes, or what is termed *animal* heat; a subject we shall have to consider in a future part of this volume.

We have thus endeavoured to give a summary view of the phenomena, and laws of motion of heat, and of light. In conclusion it only remains to observe that these phenomena and laws are all of the utmost importance in the economy of nature, as constituting limitations and principles of action, to which the Great Author of nature most rigidly adheres in his operations. Hence, whether we view the distribution of heat and of light on the large scale, as regulating climate; or whether we view them with reference to the most trifling particular, as the clothing of a bud or of an insect; we find the same beautiful adaptation and contrivance, everywhere exemplified, to ensure or to evade the agency of these all-important principles. The wonderful arrangements connected with heat and light will however fall more naturally to be considered hereafter; we shall therefore defer what we have to say on these subjects till we come to speak of meteorology.

Section IX.

Recapitulation and General Observations on the Subjects treated of in the preceding Chapters.

In the preceding observations we have endeavoured to give a connected sketch of the nature and operation of molecular forces; and perhaps it will still further facilitate the understanding of the subject, if we recapitulate briefly the leading facts, so as to point out to those who may not be inclined to peruse the foregoing details, the analogy that prevails throughout the whole.

1. In the first place we attempted to show that the forces which determine molecular union can scarcely be those of mere gravitation, in their ordinary forms at least; but that some other modification of force is necessary to account for the phenomena.

2. By assuming the molecules of bodies to be virtually spheroidal, and endowed with two kinds of polarizing forces, the one operating *axially*, and the other *equatorially*, we attempted to show how the phenomena of simple crystallization might be explained; and we corroborated our argument by demonstrating that the electric and magnetic forces are actually related to each other, precisely as we assumed the energies of our molecules to be. Hence we ventured to draw the conclusion, that electricity and magnetism, if not identical with, at least represent, or are analogous to those forces, the existence of which among ponderable bodies we assumed as necessary to account for the phenomena of crystallization. Further we attempted to render it probable, that the molecules of the imponderable principles, heat and light, possess polarities precisely analogous to those of ponderable bodies, and that many of their peculiar phenomena depend upon these polarities.

3. In attempting to account for the different forms assumed by bodies, we supposed that in the *solid* form, the molecules are so arranged as to attract each other according to certain laws; that in the *liquid* form, they are so arranged as neither to attract nor repel each other; and that in the *gaseous* form, the arrangement of the energies of the molecules is such as to render them mutually repulsive. Further, by assuming that those molecules which possess the property of attracting each other in the solid form in preference to others, retain a similar relation in the gaseous form, and repel each other in preference to others, we attempted to account for many of the well known phenomena of gaseous bodies.

4. Lastly, we attempted to show that the phenomena of *radiation* among the molecules of imponderable bodies, are precisely analogous to the phenomena of diffusion and mixture among the molecules of ponderable bodies when in the liquid and gaseous states; and that consequently the same laws are strictly applicable to both.

With respect to the reasons which have induced us thus to enter into the dry details of molecular action, and which may seem to require some apology to our readers, they are chiefly two-fold: In the first place, as connected with the particular business of the present treatise, it has been our object to convey to the general reader some idea of the wonderful operations which are constantly taking place in every particle of matter which he sees around him, or to use the language of Paley, some notion of the "concealed and internal operations of the machine." These operations may not be as we have represented them; they may in fact be altogether different; but be this as it will, a perusal however cursory, of what has been stated, can hardly fail to ac-

complish one purpose we had in view, viz: to show to the most incurious and superficial reader that in the minutest fragment of matter, and in the commonest and simplest operations which take place in nature, and which he is altogether too apt to overlook, the most wonderful and extraordinary arrangements, *must* take place; arrangements which, if duly considered, are calculated fully as much, if not more, than those connected with the more striking and obvious phenomena, to excite his wonder, and at the same time to display the wisdom and power of the great Creator. The second object we aimed at, was, as just stated, to give a connected and popular sketch of molecular forces and operations; and by placing them in a point of view in which we believe they have not hitherto been considered, to display the beautiful simplicity and analogy that prevail throughout the whole.

Finally, it remains, before we close, to state briefly the arguments deducible from the divisibility and molecular constitution of matter, with reference to our present subject. These arguments may be considered under the three following heads; first, that matter has not *always* existed in its present form; secondly, it could not have existed in its present form by *chance;* and thirdly, and consequently, that it must have been the work of a voluntary and *intelligent* Being. Other deductions might doubtless be made from what has been stated, but these we purposely avoid, and confine our arguments as much as possible to grounds admitting of no controversy.

In the first place, the divisibility and molecular constitution of matter seem to prove beyond a doubt that it cannot have *eternally* existed in its present state.

Although we can form no idea of what matter would be without its molecular properties, there is yet nothing in these properties which can induce us to believe that they are *necessary* to the mere *existence* of matter. On the contrary, we have seen that matter possesses qualities (those of gravitation) of a more primordial kind, to which its molecular properties are apparently secondary or subordinate. But if these subordinate properties be not necessary to the existence of matter, matter might *possibly* at some time have existed without them. Now this very possibility is incompatible with eternal existence; for eternal (passive) existence necessarily involves incapability of change. Hence the molecular constitution of matter, even in this point of view, must be supposed to have had a beginning; and when we consider the leading and characteristic property of matter in the molecular state, viz. *the endless repetition of exactly similar parts*, the difficulty of arriving at

any other conclusion is exceedingly increased. It is to be observed also that the above remarks apply to the supposition of only *one* form of matter; but we shall see hereafter that chemists recognize upwards of *fifty* forms of matter, all of an elementary character; at least we cannot at present say that one of these forms is more elementary than another. Again, the number of molecules in each of these elementary principles, great as it is, is *limited;* the properties of the molecules also are fixed and definite, all which circumstances throw further insurmountable difficulties in the way of the supposition, that the whole have existed, as they now exist, from eternity. For how has it happened, it may be asked, that the number and properties of the elements, and the molecules of which they consist, are just what the economy of nature requires, and neither greater, nor less, nor different? How has it happened, that what is supposed to be infinite in some respects, should be finite and limited in those respects in which we are actually able to trace them; and what is more, most luckily finite and limited just where they appear to be required to be so? He who can satisfactorily answer these questions may contend with some prospect of success for the eternity of matter and its properties in their present form. In the mean time we assert without fear of contradiction, that the molecular constitution of matter is decidedly artificial; or to use the words of a celebrated writer, that the molecules of matter have all "the essential characters of a manufactured article,"* and consequently are not eternal.

Secondly, if the present molecular constitution of matter has not always existed, it must have been produced at some time, by some cause superior to itself. Now this cause must have operated either accidentally and by *chance;* or voluntarily and under the influence of a *will.*

With respect to the first of these alternatives, viz. chance; the *endless repetition of similar parts* presented by the molecular constitution of matter seems absolutely to preclude this supposition. Do we not consider it a subject of wonder to see even two or three things by chance alike, as for example two or three human faces? Should we not consider the man absolutely mad, who would attribute the uniform and manœuvres of a regiment of soldiers to chance? and can we then resist the argument in the infinitely stronger shape in which it is here presented to us! Thus, as the idea of chance seems too monstrous to be entertained for a moment by any rational being we are driven irresistibly to the other conclusion, viz. that the cause or agent who formed the molecular constitution of matter was a *voluntary* agent or *Being*;

* Sir J. Herschel on the Study of Natural Philosophy, p. 38.

and moreover that this Being possessed a *power* commensurate with his will.

Thirdly; the agent or Being who constructed the wonderful system we have been considering must have been as *intelligent* as he was powerful.

We infer intelligence in an agent from the fitness and adaptation to certain ends exemplified in his works. Thus, when we see a machine admirably fitted for the office it performs, we infer that the maker of that machine must have possessed intelligence. Now if we judge of the molecular constitution of matter by this rule, we shall find that there is not only the most extraordinary fitness and adaptation to circumstances displayed in its arrangements, as far as we can understand them, but evidently much further; that is to say, the maker of this system must not only have possessed intelligence, but intelligence infinitely surpassing our own. Thus at the very beginning, the selection of the molecular form of matter out of the many possible forms which might be supposed to exist, may be considered as an instance of intelligence of the highest kind; for this alone, of all the forms that can be conceived, seems best adapted to the purposes of creation. Indeed, on what other supposition, than that of the subdivision of matter into *minute similar parts*, could all those endless operations which we see constantly going on in the world, be imagined to take place? Moreover, the nature of the powers with which the molecules of matter are endowed is truly astonishing, and calculated in the highest degree to impress us with exalted notions of the intelligence and power of their contriver. Thus, what can be more wonderful, than that the self-same *chemical* forces differently directed should produce, not only all that endless change of property, of form, and of condition which we see around us, and which are so beneficial and even necessary to our existence; but likewise some of the most terrible displays of power in nature; as for instance, the utmost intensities of heat, of cold, and of light; the terrors of the thunderbolt, and the irresistible energies of the earthquake! Nor on the other hand, are the *cohesive* affinities existing among the molecules of matter much less wonderful or important; for if *similar* molecules had not been constituted with self-attractive and self-repulsive powers, there would have been no aggregation of the same matter into symmetrical groups, no order or regularity, no separation or purity; in short there would have been no common bond of union, and the whole would have been dispersed throughout nature, as accident or other circumstances might determine. Hence the present order of things could not have existed unless the molecules of matter had been endowed with *both* these properties;

one of which the *chemical*, as it were, goes before and imperiously determines what molecules shall be combined or separated; while the other, the *cohesive*, silent and unobtrusive, follows in its train, and industriously assorting and arranging its predecessors' labours, here perhaps forms a diamond, or there superintends the integrity of the atmosphere!

Such are molecular forces as they obviously appear to us, and such the arguments deducible from them. But when we attempt to go further, and inquire into the intimate nature of these forces, we not only find much that is unknown to us, but much that apparently surpasses our utmost conception! And what a still more sublime idea is this calculated to convey to us of the wisdom and power of that Being who contrived and made the whole! When and where, do we naturally exclaim, did this Being exist? whence his wisdom, and whence his power? There is, there can be, but one answer to these inquiries. The Being who contrived and made all these things must have pre-existed from eternity—must have been omniscient—must have been omnipotent—MUST HAVE BEEN GOD!

CHAPTER IV.

OF CHEMICAL ELEMENTARY PRINCIPLES, AND OF THE LAWS OF THEIR COMBINATION.

IN the preceding chapter we have endeavoured to show that the minutest fragment of homogeneous matter cognizable by our senses is composed of innumerable molecules, all of which are exactly alike in size, in shape, in properties, in short, of every kind; and we argued that these facts incontestibly prove that these molecules could not always have existed in their present form, nor have been formed by chance, but that they must have had a beginning, and have been the work of a Creator. Now when we consider the prodigious quantity of matter composing our globe (to go no further) or even composing a portion of it, as for example, the mass of water existing in the ocean, and reflect that every individual molecule of this water possesses properties exactly like those of the drop we formerly contemplated, our argument, already sufficiently convincing, actually overwhelms us with its force. Still however it admits of further corroboration; and we proceed now to show that all this vast assemblage of molecules, so numerous, so diversified, so extraordinary as they are, may be reduced to a very few elementary

groups, upon the endless combinations and separations of which all the phenomena of chemistry depend.

Section I.

Of Chemical Elementary Principles.

The substances at present considered as elementary amount to about fifty-four. Of these several possess certain properties in common, though they all differ from one another in subordinate particulars, or in other words, are specifically different. Of the whole number not above two or three exist in any great quantity in an uncombined state, at least in those parts of our globe to which we have access, but the whole are wrapped up as it were and have their properties concealed in compounds. Under ordinary circumstances most elementary principles exist as solids, but some of the more important occur in a gaseous form, and one or two as fluids. A few of them are *apparently* of so little consequence in the world, that if they were annihilated they would scarcely be missed; while others of them, on the other hand, are so obviously necessary to the existence of the present order of things, that the least derangement or alteration in their proportion or quantity would be fatal to the whole. Some of these elementary substances exist in such enormous quantities as to constitute a large proportion of the whole visible bulk of our globe, while others again, occur in such minute proportion, at least within our reach, as to be obtained with difficulty and not without elaborate research. With respect to the facility with which they enter into combination, and the obstinacy with which they unite, they differ also very remarkably; a few of them combining readily in a variety of proportions with almost all the rest, while some of the others can be scarcely made to combine under any circumstances. Lastly, with respect to the influences which different elementary substances are capable of exerting upon organic life, these are equally striking. A large majority of them indeed may in their simple state, be considered of a deleterious nature: while three or four of them, on the other hand, make organized beings what they are, and are necessary to their very existence.

Such are a few of the leading properties of the elementary principles as we are at present acquainted with them; in the following table from Dr. Thomson they are arranged, as far perhaps as is practicable, according to their chemical characters.

TABLE.

1 Oxygen.	14 Arsenic.	27 Calcium.	41 Zinc.
2 Chlorine.	15 Antimony.	28 Magnesium.	42 Cadmium.
3 Bromine.	16 Tellurium.	29 Strontium.	43 Lead.
4 Iodine.	17 Chromium.	30 Baryum.	44 Tin.
5 Fluorine.	18 Uranium.	31 Aluminum.	45 Bismuth.
———	19 Vanadium.	32 Glucinum.	46 Copper.
6 Hydrogen.	20 Molybdænum.	33 Yttrium.	47 Mercury.
7 Carbon.	21 Tungsten.	34 Zirconium.	48 Silver.
8 Azote.	22 Titanium.	35 Thorinum.	49 Gold.
9 Boron.	23 Columbium.	36 Iron.	50 Platinum.
10 Silicon.	———	37 Manganese.	51 Palladium.
11 Phosphorus.	24 Potassium.	38 Nickel.	52 Rhodium.
12 Sulphur.	25 Sodium.	39 Cobalt.	53 Iridium.
13 Selenium.	26 Lithium.	40 Cerium.	54 Osmium.

It is foreign to the object of this work to enter into a minute description of these bodies ; we shall therefore content ourselves with such a view of them as may enable the general reader to form some idea of their properties, and to follow us without much difficulty in our subsequent remarks.

The five first bodies, *Oxygen*, *Chlorine*, *Bromine*, *Iodine*, and *Fluorine*, are usually termed supporters of combustion. They have some properties in common, though in other respects, and particularly in their apparent relative importance in the economy of nature they differ exceedingly. They are remarkable for the tendency they have, not only to combine with one another, but with almost all the bodies below them in the table ; and their union, particularly that of oxygen, is usually accompanied with the extrication of more or less of heat and light, and constitutes the well-known phenomena termed *combustion*.

(1) *Oxygen* is one of the very few elementary substances that occur naturally in the gaseous form, in which form it constitutes about one fifth part of common air. As the world at present exists, oxygen, perhaps, may be fairly considered as one of the

1. Oxygen, from ὀξὺς, acid, and γεννάω, to generate ; from its property of forming acids. 2. Chlorine, from χλωρὸς, green ; so called from its colour. 3 Bromine, from βρῶμος, fetid ; so called from its strong odour. 4. Iodine, from Ἰοειδὴς violet ; from the colour it assumes in the gaseous state. 6. Hydrogen, from ὕδωρ, water, and γεννάω, to generate. 8. Azote, from *a* privative and ζωὴ, life ; from its being incapable of supporting life. 13. Selenium, from Σελήνη, the moon. 17. Chromium, from χρῶμα colour ; so called from the beautiful colours of some of its salts. 18. Uranium, from οὐρανὸς, the heavens. 19. Vanadium, from *vanadis*, a Scandinavian deity. 20. Molybdænum, from Μολύβδαινα, lead. 22. Titanium, from Τίτανος, calx. 23. Columbium, from Columbia, in America, where it was first found. 26. Lithium, from Λίθος, a stone. 29. Strontium, from Strontian, the name of a place in Scotland, where first found. 30. Baryum, from

most important, if not the most important substance in it. From its proneness to enter into composition it is constantly operating upon, and modifying everything. By far the greater proportion of mineral bodies forming the crust of the earth, contain more or less of it; and in all plants and animals it actually exists as a constituent elementary principle. In short, the properties of oxygen stamp it as an element and subordinate agent of the most important kind; while the numberless contrivances which are observable in nature, to secure, or evade, or modify its operations, are most extraordinary, and exhibit some of the most marked and unequivocal evidences of design on the part of their great Contriver, that we meet with among his works. Several of the most important of these contrivances we shall have occasion to allude to hereafter; but there is one of so curious and interesting a character that it may be mentioned here as an illustration of the above remarks. The nature and mechanism of the function of respiration will be explained elsewhere, and it is sufficient for our present purpose to state that, by means of a complicated apparatus, the blood is made to circulate through the lungs, in order that it may be there exposed to the oxygen of the atmosphere. For purposes beyond our comprehension, but probably in part at least with a view to the future creation of organized beings, the great Architect of the universe had willed that this principle should exist upon the surface of our globe in a gaseous state; when he created animals he chose also to render them dependent upon oxygen for their existence; and he effects his object, not by bending this principle to his purpose, by altering its physical or other properties; not by obtaining it from water, or any of the innumerable compounds into which it enters, which according to our imperfect notions he might have more easily done; but, as if on purpose to display his power and design, he rigidly adheres to the properties, both mechanical and chemical, imparted to oxygen, and to these properties accommodates his future labours! The whole therefore of the complicated and beautiful apparatus, connected with the respiration of animals, is most obviously designed and constructed with reference to the properties of the oxygen of the atmosphere, and altogether they afford one of the most striking evidences of adaptation and design presented to us in nature.

(2) *Chlorine* in its elementary state is a gas, having all the

Βαρὺς, heavy. Aluminum, from Alumen, alum. 32. Glucinum, from Γλυκὺς, sweet; from the taste of some of its salts. 52. Rhodium, from Ῥόδον, a rose; from the colour of some of its compounds. 53. Iridium, from Ιρις the rainbow; from the variety of colours assumed by some of its salts. 54. Osmium, from Ὀσμὴ, odour; from the strong smell emitted by some of its compounds.

mechanical properties of common air, but in this form it never occurs naturally. It exists however in great abundance in a state of combination, from which it may be readily obtained by easy chemical processes. One of the most abundant sources of chlorine is *common salt*, into which it enters in the proportion of about 60 per cent. As compared with oxygen chlorine is much less abundant and perhaps important; yet it is doubtful if without chlorine the present order of things could proceed. Take for example the familiar instance of common salt above referred to. Let us consider the universal diffusion of this substance throughout nature—what the sea would be, or how animals could exist, without it—let us consider these and the numberless other operations which this valuable compound more or less enters into, or influences, and we shall be able to form some notion of the part chlorine bears in the economy of nature. On the other hand, when we reflect that were chlorine to be extricated from its state of combination, and made to exist, like oxygen, in a gaseous form, that it would instantly prove fatal to organized beings; can we fail to be struck with the very obvious design thus displayed in rendering its quantity and combining powers such as to keep it in a state of union, and by these means to secure all its useful without its deleterious properties?

(3) (4) *Bromine* and *Iodine*, the next two substances, are found principally in sea-water and in marine productions. They appear to exist in very minute proportion, and always in a state of combination. *Bromine* exists under ordinary circumstances as a deep-coloured red fluid, having a very strong and offensive odour; *Iodine* is a crystallized solid, volatile by a slight increase of temperature, and forming a beautiful violet vapour. Bromine and Iodine more nearly resemble chlorine than oxygen in their properties, though they differ materially from both, and their use in the economy of nature is absolutely unknown. It may however be observed that *Iodine* has lately been much celebrated for its medicinal properties.*

(5) *Fluorine* has been rather inferred than demonstrated to exist. It occurs principally in the mineral called *Fluor spar*, in

* It may not be amiss to observe here that the author of the present volume first employed the hydriodate of potash, as a remedy for goitre, in the year 1816, after having previously ascertained, by experiments upon himself, that it was not poisonous in small doses as had been represented. Some time before the period stated, this substance had been found in certain marine productions; and it struck the author that burnt sponge (a well known remedy for goitre) might owe its properties to the presence of Iodine, and this was his motive for making the trial. He lost sight of the case in which the remedy was employed, before any visible

a state of combination with lime, and in this state it would seem to be harmless; but in a state of purity it is exceedingly deleterious. One of its most remarkable properties is that of corroding glass.

We pass on now to a very different class of substances, and which instead of having the power of supporting combustion in other substances, are for the most part themselves combustible. Of these, the first and perhaps the most important we have to notice is

(6) *Hydrogen.* This principle in its elementary state exists as a gas, having all the mechanical properties of common air. In this state it is exceedingly inflammable; and if mixed with oxygen, and if the mixture be exposed to heat, the two gases unite suddenly and violently with a loud explosion; while the result of the combustion is *water.* Hydrogen is the lightest body known, and under the same bulk therefore contains less matter than any other body. It does not exist naturally in a separate state, but always in combination; and by far most generally and abundantly in combination with oxygen in the form of water. Hydrogen ranks perhaps next to oxygen in importance; at least as far as organized beings are concerned; since like oxygen it constitutes one of the elementary principles of which they are formed. It differs however remarkably from oxygen, in not being in its elementary state necessary to the existence of organized beings; indeed hydrogen is actually incompatible with the existence of animals, if not of vegetables; and its properties as an element have evidently been sacrificed to its properties as a compound, that is to say, to its properties as *water.* Hence we have to admire the happy adjustment of the quantities of the two elements to each other, so that the oxygen shall predominate; an adjustment that can scarcely be explained upon any other supposition than that of design; for any other cause, as chance, would have been quite as likely to have produced an excess of hydrogen as of oxygen, or at least anything but the exact proportions required. Lastly, it may be remarked, that to the relative proportions of oxygen and hydrogen existing on our globe, more than perhaps to any other subordinate cause, the present order of things owes its stability. For the proportions of these principles are so happily adjusted and balanced, and all the numerous operations dependent upon them are, in consequence, so

alteration was made in the state of the disease; but not before some of the most striking effects of the remedy were observed. The above employment of the compounds of Iodine in medicine was at the time made no secret; and so early as 1819, the remedy was adopted in St. Thomas's Hospital, by Dr. Elliotson, at the author's suggestion.

firmly established, that no material change can possibly happen to any part from an internal cause, but if changed at all, the whole must be changed from without.

(7) *Carbon*, or charcoal, is a substance too well known in its ordinary state to require description; in its crystallized and pure state it is found to constitute the *diamond*, the hardest and most brilliant body in nature; a circumstance that certainly could not have been anticipated, but which affords a most striking instance of the effects produced by the different modes in which molecules of the same matter may be aggregated. Carbon perhaps more than any other principle may be considered as constituting the staminal or fundamental element entering into the composition of organized beings. This is particularly the case in principles from the vegetable kingdom, which owe their peculiar character essentially to carbon, and their endless varieties to differences in its quantity, and to the modifying influence of the hydrogen and oxygen with which it is associated. In animal substances, carbon exerts a similar influence, but its effects are materially modified by the presence of another staminal principle to be presently considered. Carbon, in some state or other, exists in considerable quantities upon the surface of our globe, but apparently by no means in so large a proportion as oxygen and hydrogen. Exclusively of that actually involved in the composition of organized beings, carbon is met with nearly pure in large quantities in particular districts in the well-known form of *fossil coals;* but it occurs in far greater proportion in combination with oxygen in the form of *carbonic acid;* which carbonic acid in union with lime, constitutes common *chalk* and *limestone*, two of the most abundant minerals in nature.* Carbon in its elementary state, is a very inert substance, and is scarcely liable to be affected by, or to affect organized beings; but with hydrogen and oxygen it forms gaseous compounds of great activity, and capable of proving instantly fatal to animals respiring them. Such effects, however, appear to be obviated by a beautiful expedient which we shall have occasion more particularly to notice hereafter. In the mean time it may be observed, that though the compound of carbon and oxygen (*carbonic acid*) is by innumerable processes constantly forming around us in enormous quantities; by some compensating means it disappears as fast as it is formed; so that

* In order to give some idea of the proportion in which carbon exists in different common substances, it may be observed that a pound of charcoal is equal to, and is contained in rather more than, two pounds of sugar or flour, and eight of potatoes or limestone; so that a mountain of limestone contains the essential element of at least an equal bulk of potatoes, and of a forest that would amply cover many such mountains.

the atmosphere, which without this provision would probably before now have become contaminated by carbonic acid to an extent fatal to animal life, barely contains traces of it.

(8) *Azote* or *nitrogen* is one of the very few elementary principles which exist naturally in an uncombined state. It constitutes about 4-5ths or 80 per cent. of common air, the rest being principally oxygen. The great bulk of this principle in existence is confined to the atmosphere, and to animal substances, of which it forms a constituent element; and it enters very little into natural mineral productions. In its pure state, azote is remarkable for its negative properties, that is to say, for the difficulty with which it enters into combination with other matters. Thus it is neither combustible nor a supporter of combustion; is neither acid nor alkaline; possesses neither taste nor smell; nor does it directly combine with any other known substance. Yet when made by peculiar management to unite with oxygen, hydrogen, or carbon, azote forms some of the most energetic compounds we possess: thus, *mixed* with oxygen it forms atmospheric air, as before observed; *united* with oxygen it forms *aquafortis*, the most corrosive of liquids; *united* with hydrogen it forms the *volatile alkali* or ammonia, likewise an energetic compound, but of an opposite nature; while united with carbon and hydrogen, it forms *prussic acid*, the most virulent poison in existence! Azote may be considered as constituting the characteristic element of animal substances, and as imparting to them their peculiar properties; in this point of view therefore it is a principle of very great importance. Moreover, the above mentioned negative properties of azote are evidently of a primordial kind, and seem to have been formed with reference to future creations, which have all been most carefully and rigidly adapted to them. Thus had the properties of azote not been negative, those of its most important compound, atmospheric air could not have been negative; and atmospheric air might have been acid or alkaline, or have possessed odour or colour; either of which circumstances would have been incompatible with the present order of things.

(9) (10) *Boron* and *Silicon*. The next two substances obtain their names from *borax* and *silex*, the natural productions in which they exist in a state of combination. Borax is a saline production chiefly found in certain lakes in Thibet and China. Boron, the elementary substance obtainable from it, is a deep brown powder possessing neither taste nor smell, but highly inflammable at a temperature below a red heat. Silicon is the elementary basis of silex or common flint, one of the most abundant minerals in nature. Silicon is a brown powder very similar to boron in appearance, and like it inflammable under certain circumstances. These two

elementary principles do not exist naturally, but have been formed by elaborate chemical processes in small quantities only. They seem to be more nearly allied to carbon, in their properties, than to any other elementary product. Borax exists in very small quantities, and its use in the economy of nature is not apparent. Silex on the other hand is a most important production, and in its hardness, insolubility, and other refractory properties, we recognize a substance admirably adapted for the purpose to which it has evidently been designed, viz. that of constituting the stamina or ground-work, as it were, of our globe, and which could not be withdrawn without subverting the whole. Silex is found in small quantities both in plants and in animals, but does not, like hydrogen, oxygen, carbon, and azote, form a constituent element of organized beings.

(11) *Phosphorus*, under ordinary circumstances, is a pale amber-coloured substance, very like wax in appearance, but so exceedingly combustible that it cannot be heated, much less melted in the open air, without immediately taking fire. Under these circumstances, as may be supposed, it does not exist naturally, but is obtained by an elaborate process from various compounds into which it enters ; as for example, from *bone earth*, or the earthy basis of the bones of animals ; and also from certain salts. It exists also in the mineral kingdom in certain districts in considerable quantities, but upon the whole, it is not an abundant principle. Phosphorus affords another beautiful instance in which the design has been directed to the properties of the compound, rather than to the element itself. The *phosphate of lime* or bone earth was apparently the thing wanted to constitute the bony skeleton of animals, and accordingly, to this compound the properties of the element itself seem to have been sacrificed. Neither lime itself in mass, nor any of its mineral compounds, appear to be adapted for forming a constituent principle of a living organized being. It was necessary therefore to have a connecting medium, or link, that should unite organization with the mineral constituent, and phosphorus admirably accomplishes this object. Accordingly, we see that organization goes on in conjunction with lime in the bones of animals, through the medium of this element, quite as readily as in other parts of their system ; whereas when phosphorus is absent, as in shells, and in other deposits of carbonate of lime, the carbonate of lime is extravascular, and seems to form no part of the living system. There are also other important offices which this principle evidently performs in the animal economy, some of which we shall have occasion to refer to hereafter.

(12) *Sulphur*. This well known substance is one of the very few that exist naturally in an elementary state. It is a very abun-

dant and probably important principle in the economy of nature, as it not only exists in large quantities in the mineral kingdom, but in a greater or less proportion in almost all animal, and in many vegetable products. Its uses, however, at present, are very imperfectly understood. Sulphur combines with hydrogen, and forms a very deleterious gaseous compound. Its combinations with oxygen are generally acid, and very active in their concentrated form, but not poisonous.

(13) *Selenium*, the next substance, is found in very minute quantities generally associated with sulphur, which in its properties it somewhat resembles ; or rather, perhaps it appears to constitute the connecting link between sulphur and the metals. The uses of selenium in the economy of nature are unknown , but we shall have occasion hereafter to refer to its compound with hydrogen, which is even more deleterious than the compound of sulphur with this element.

(14) *Arsenic* in its pure state is a metalloid, or imperfectly metallic substance, having much the appearance of polished steel. In the form in which it is popularly known, as *white* arsenic, it is combined with oxygen, and constitutes one of the most virulent of poisons. Arsenic exists in certain minerals in considerable quantities, and seems in every form, to be incompatible with organic life.

(15) *Antimony* is usually found in nature associated with sulphur, the compound it forms with which, was for a long time considered as the metal itself. In its pure state, antimony has a bluish-grey colour, and possesses considerable metallic splendour, but in this form it seldom occurs in nature. The compounds of antimony are active medicinal agents, and some of them are much employed for that purpose.

(16) (17) (18) (19) (20) (21) (22) (23) *Tellurium*, *Chromium*, *Uranium*, *Vanadium*, *Molybdænum*, *Tungsten*, *Titanium* and *Columbium*, the next eight substances, are metals, for the most part obtained by elaborate processes from rare mineral productions. The most important, as well perhaps as the most abundant of these substances, is chromium, the compounds of which, from the splendour of their colours, have been lately much employed in the arts. It may be remarked of all these substances, that at present their use in the economy of nature is quite unknown to us.

(24) (25) *Potassium* and *Sodium* are the metallic bases of the two well-known alkaline substances, *potash* and *soda*, which are compounds of these metals with oxygen. Such, however, are the powerful affinities of the metallic bases for oxygen, that they nowhere exist naturally upon the surface of our globe. The same may be also remarked of potash and soda, the powerful alkaline properties of which prevent them from existing separately. In

this respect, the compounds these metals form with oxygen, present a striking contrast with the compounds they form with the analogous principle, chlorine ; the compounds of potassium and sodium with chlorine (the latter of which constitutes common salt,) are remarkable for their fixed and permanent character, and for the little tendency in general which they have, to enter into a further state of combination. Besides their remarkable avidity for oxygen, potassium and sodium possess some other unusual properties. Potassium, for example, is so light, that were it compatible with water, it would swim on the surface of that fluid ; a circumstance we can hardly imagine to happen with a metal. Potash and soda in all their forms are most important principles, and evidently are necessary to the existence of the present order of things, both mineral and organized ; for there are few organized beings that do not contain more or less of them, especially of soda. Potash is found more particularly in plants, but exists also in animals ; while the universal presence of soda in animals, in the form of common salt, has been already referred to, and is generally known. These alkalies present us with a beautiful instance of adaptation, for the purposes which they seem destined to fulfil in the operations of nature. Had they been solids, or had they formed solid compounds, like many of the preceding principles, they would have been totally unfitted for their peculiar office, that is to say, for forming a constituent element of the fluids of organized beings.

(26) *Lithium* is the metallic basis of *lithia*, a substance recently discovered, and intermediate in its properties between the alkalies and the earths to be next considered. It has hitherto been met with, in some rare minerals, in small quantities only.

(27) *Calcium*, the metallic bases of *lime*, can be obtained only by a troublesome and difficult process, and of course does not exist naturally. It is a white metal like silver, and by union with oxygen is readily convertible into lime. This well known principle exists in the greatest abundance in nature, not as quick-lime, but united with carbon and oxygen, in the form of common limestone, marble, &c. The great importance of lime in the economy of nature is too obvious to require notice, and it is only necessary to revert to the fact that this earth is one of the very few mineral productions capable of forming a part of a living organized being; at least in any quantity. This earth, as formerly noticed, constitutes with phosphorus and oxygen, the basis of the bones of animals ; and with carbon and oxygen, all the endless variety of shells and similar products. Thus the properties of lime furnish another striking instance of adaptation to a particular purpose. The compounds of potash and soda are all very soluble in water, and hence are chiefly confined to the *fluids* of animals, in which their pre-

sence is indispensable. But a solid frame-work or skeleton was necessary to the existence of the more perfect animals, and as this could not be formed from the soluble potash or soda, the introduction of another mineral substance possessed of the requisite properties was necessary. Now lime, some of the compounds of which are *solid* and some *fluid*, is admirably adapted for the purpose; and lime accordingly has been chosen: the lime is carried, in a state of solution, to the spot where it is required, and is there converted into a *solid;* while by the same agency, when necessary, this solid is again converted into a fluid and removed! It seems impossible to conceive arrangements to present more striking evidences of adaptation than these; and the more we consider the subject in all its bearings, the more wonderful does it appear.

(28) *Magnesium* is the metallic basis of the well-known earth called *magnesia.* It is said to resemble calcium in its properties, and like that principle does not exist naturally, at least upon the surface of our globe. Magnesia, though occurring most abundantly in nature, and entering very largely into the composition of rocks, does not, like lime, constitute masses of great extent in the same simple state of combination; that is to say, there are no mountains of magnesia, as there are of chalk and of limestone. Magnesia, even more decidedly than the three preceding mineral substances, seems to be necessary to the existence of organized beings; as there does not appear to be one, in which traces of this earth are not met with, generally associated with phosphorus. Its uses, however, are less obvious than those of the three other substances, and indeed may be said to be unknown; though there is reason to believe that it is most intimately connected with the vital operations of organized beings.

(29) (30) *Strontium*, and *Baryum*, the metallic bases of the two earthy bodies *strontia* and *baryta*, are allied to calcium and magnesium in some of their properties, but differ exceedingly from them in others. Their combination with oxygen exhibit still more decidedly alkaline powers than those of either calcium or magnesium, and in consequence, like them, they only exist in various states of combination; and most usually with carbon and oxygen, or with sulphur and oxygen. Compared with lime and magnesia, strontia and baryta exist but sparingly, and neither of them has anything to do with organization; indeed many of the combinations of baryum are virulent poisons.

(31) *Aluminum* is the metallic basis of the earth *alumina*, the characteristic ingredient of the well known salt called *alum.* The metallic basis, like the preceding, nowhere exists; but alumina, the compound of aluminum and oxygen, is one of the most abun-

dant productions of nature, and constitutes an ingredient in by far the greater number of rocks and soils upon the surface of the globe. The different kinds of clay, also, of which bricks, earthenware, &c., are formed, consist chiefly of this earth in different states of purity; so that it is a substance of great utility and importance. Alumina appears to have nothing to do with organization; at least it is not known to form a necessary constituent of any organized being, either vegetable or animal; though it is in constant communication with organized beings, and appears to be almost necessary, in some indirect way, to their existence. This fact is very remarkable; for as the earth does not appear to be poisonous, it could scarcely have been so completely excluded from living bodies, except by some design beyond our comprehension.

(32) (33) (34) (35) *Glucinum, Yttrium, Zirconium, and Thorinum*, the four next elementary principles are the metallic bases of substances, usually considered as possessing the characters of earthy bodies, and denominated *Glucina, Yttria, Zirconia*, and *Thorina*. They all appear to exist very sparingly in nature, and are only met with in some rare minerals. Glucina has been hitherto met with only in the precious stones denominated the *emerald*, the *beryl*, and the *euclase;* yttria and thorina in some rare Swedish and Norwegian minerals; and zirconia in the *jargon* or *zircon* from Ceylon, and in the *hyacinth*. These earths more nearly resemble alumina than any other substance.

(36) *Iron*, one of the most important, is also one of the most abundant principles in nature. It is met with occasionally in the metallic state, but most generally it is found mineralized in various ways, and can only be obtained pure by an elaborate process. Iron exists in minute quantities in almost all vegetable and animal products, particularly in the blood; though its mode of combination, as well as its precise use, are quite unknown. Iron may justly be considered as the most useful of all the metals, and the one that has perhaps contributed more towards the civilization of mankind than any other. To form some idea of its use, we have only to reflect what would happen if it were annihilated. What substitute could be found for it in all the numerous instances in which it contributes to the wants or to the comforts of mankind; particularly through the medium of tools, of almost every one of which it constitutes the essential material. In short, when we contemplate all the circumstances connected with this metal, its abundance, the manner in which it is mineralized, and the occasion which it thus gives to human ingenuity to extract it from its ores; its wholesomeness (for many of the metals are poisonous); its properties, particularly its extraordinary tenacity; its strength,

its property of welding, of being converted into steel, and in this form of being tempered to any degree of hardness we choose; its magnetic properties, &c.,—when we contemplate all these circumstances, it is impossible not to be struck with such varied usefulness, and to consider iron, not only as an article evidently designed for the benefit of man, but as the instrument by which he should conquer and govern the world; and thus be enabled to place himself, where it was evidently intended he should be, at the head of the creation.

(37) *Manganese* somewhat resembles iron in a few of its properties. It may be obtained from its ores by an elaborate process, but in this form it is little known or used. Manganese exists in minute quantities in certain mineral waters, and in a few animal products; and its combinations with oxygen, are not only employed in the arts, but by the chemist, who frequently procures oxygen for his experiments from the ores of manganese. Though much diffused, manganese is not a very abundant metal, at least compared with iron, and its uses in the economy of nature are apparently much less important.

(38) (39) *Nickel* and *Cobalt*, are two metals somewhat resembling each other in a few of their properties, and their ores are often associated in nature. It is remarkable also that they are both generally found combined with iron in those bodies, which occasionally fall from the atmosphere, and which are considered as of meteoric origin. Like iron also both these metals are capable of becoming magnetic. Cobalt is used in the arts, and is the basis of the blue colour upon our earthenware; but neither this metal nor nickel are to be compared with iron in point of utility, nor are they very abundant productions.

(40) *Cerium* is a metal very little known, and has hitherto been obtained, in minute quantities only, from some rare minerals occurring in Sweden and in Greenland.

(41) (42) *Zinc*, *Cadmium*. These two metals are generally associated in nature, and somewhat resemble each other in eitrh properties; but the last is comparatively much less abundant, and has been only recently discovered. Zinc is a metal easily fusible, of a bluish white colour, and of a lamellated brittle texture; though by peculiar management it may be rendered malleable. It is an ingredient in the well-known compound metal, *brass*, and in this form is much used and is of considerable importance.

(43) *Lead*. This well-known metal is not found in its metallic state, but its ores are very abundant, and most of the lead of commerce is extracted from the mineral called *galena*, which is a compound of lead and sulphur. The general properties of lead

and of its compounds render it of considerable importance; but its poisonous properties are a considerable draw-back to its usefulness. Why lead, and other mineral matters, should have been constituted poisonous is a question beyond our reach; and all we can at present venture to state on this and on similar points is, that it is not actually necessary that man should employ lead or other poisons, and that he may, if he chooses, avoid their deleterious properties.

(44) *Tin.* This useful metal has been employed by man from the most remote antiquity, though it nowhere exists naturally in its metallic state, but usually in conjunction with oxygen. Tin is not a very abundant metal, being apparently confined to a few localities only, one of the most noted of which is Cornwall. It is much used in the arts, and hence is of considerable importance.

(45) *Bismuth* occurs in nature both in the metallic state and in various states of combination. It has a reddish white colour and a lamellated brittle texture, and is easily fusible. Bismuth is not a very abundant metal, and is not much employed.

(46) *Copper* occurs in nature in the metallic state, but much more frequently mineralized, especially with sulphur. The valuable properties of copper, both in its pure and mixed state, render it of considerable importance; and it is in consequence much employed in the arts. With zinc it constitutes *brass;* with tin *bell-metal;* both well-known compounds. Copper has been lately said to exist in very minute quantities in organic nature, but whether as an accidental, or as an essential ingredient is not known. The compounds of copper are poisonous, but these poisonous properties, like those of lead, can be easily obviated and guarded against.

(47) *Mercury.* This well-known fluid metal occurs in the metallic state, but more frequently mineralized, especially with sulphur. Its importance in the arts, and as a medicinal agent, are too well known to require mention here. The fluidity of mercury presents a beautiful instance of the endless diversity of nature, and adds much to its importance and usefulness. Mercury exists in considerable abundance, though much less so than many of the preceding elementary principles.

(48) (49) *Silver* and *Gold*, and their uses, are too familiar to require enumeration. They are both met with in the metallic state, but silver also occurs mineralized. So unimportant a part do they seem to perform in the economy of nature, that if they were annihilated, it is probable that the world would go on just as well without them. How different in these respects from iron, and how much less therefore intrinsically valuable! Independently of their beauty, the only really valuable properties of silver

and gold are the difficulty with which they are acted on by heat and other extraneous agents, properties, which if they were more abundant, would render them well adapted for a great many useful purposes.

(50) (51) (52) (53) (54) *Platinum*, *Palladium*, *Rhodium*, *Iridium*, and *Osmium*, are metallic substances usually found associated in small quantities, chiefly in certain districts of South America, but recently also in the old world. Platinum, the most abundant and important of them, is the heaviest body in nature. It is scarcely acted on by any ordinary agents, but it may be welded by heat; properties which render it exceedingly valuable for many purposes, and make us regret that it is not more abundant. Palladium somewhat resembles platinum in its properties, but occurs in less quantity. The other three metals exist in very minute quantities, and their properties are very little known.

We have thus taken a summary view of the different elementary principles met with upon the surface of our globe, and of their leading compounds; and we are now to consider the laws which regulate the union of these principles with one another.

Section II.

Of the Laws of Chemical Combination.

As the following remarks upon the laws of chemical combination can scarcely be so given as to prove a source of interest to the general reader, he is desired to pass them over and to turn to the last section of the present chapter, where he will find a brief recapitulation of the leading facts, and of the arguments which they furnish in favour of design, and of the wisdom and power of the Creator.

In the preceding chapter we advanced a few of the leading arguments which induce us to adopt the hypothesis that *all gaseous bodies under the same pressure and temperature, contain an equal number of self-repulsive molecules;* and we have now to consider, very briefly, some of the important consequences to which this hypothesis naturally leads.

It seems to be satisfactorily established that bodies, in their gaseous state, combine both *chemically* and *cohesively* with reference to their volumes; that is to say, that the same volume of a gas always combines with either precisely a similar volume of the same or of another gas, or with some multiple or submultiple of that gas (in other words with twice, or thrice, or half, or a quarter as much, &c.) but not with any intermediate proportion; and

further, that the resulting compound always has reference by volume to the original volumes of its constituent elements. Let us take water for example. Water has been shown to consist of one volume of oxygen gas, and two volumes of hydrogen gas; and so invariably, that we cannot suppose water to be formed of any other proportions of these elements. It has been also shown that the resulting water, if in the state of steam, occupies exactly the space of two volumes, so that one volume has disappeared. Now let us consider attentively what must have happened during these changes. One volume of oxygen gas has contributed to form two volumes of water, which two volumes of water, according to our hypothesis, must consist of twice the number of self-repulsive molecules contained in the one volume of oxygen; yet every one of these molecules must contain oxygen, because oxygen is an essential element of water: it follows, therefore, irresistibly, that every self-repulsive molecule of oxygen *has been divided into two*, and consequently must have originally consisted of at least two elementary molecules, somehow or other associated, so as to have formed only one self-repulsive molecule. This conclusion, which seems to flow naturally from our premises, is most important, as we shall see immediately, and enables us to throw no small light upon many points deemed obscure. In the mean time let us consider briefly the nature of the compound self-repulsive molecule of oxygen.

We endeavoured to show in the previous chapter, that every ultimate molecule of matter must possess two kinds of polarity, which, for want of better terms, we denominated the *chemical* and the *cohesive;* and that these polarities bear the same relations to each other as electricity and magnetism; in other words that, like these forces, the polarities exist at right angles to each other. Hence if A and B be supposed to be two molecules of oxygen, of which EE *e*E represent the chemical poles and axis, and MM, *m*M the cohesive, it is evident that these two molecules may be supposed to combine in two ways, either E to *e* chemically, or M to *m* cohesively; but the latter form of course is most probable *from the similar nature of the molecules.** Every self-repulsive molecule

* The general and strong analogy, if not identity, in all respects except *direction*, between the axial and the equatorial forces, has been already alluded to, and is exemplified by the striking resemblance between electricity and magnetism. We have seen also that in the crystallized state, similar molecules probably combine *chemically*. Hence, although the rule stated in the text be true, that *similar* molecules only combine *cohesively;* yet there may be, and probably are, instances in which they combine *chemically*. For the same reasons, *dissimilar* molecules may also occasionally combine *cohesively*. It is probable that such states of combination might be readily detected by the optical properties, or by some other peculiarity

of oxygen, therefore, as it exists in a state of gas, must consist of *at least* two molecules, united to each other *cohesively*, and acting as a single one; and the same may be shown with respect to other gaseous bodies, as, for instance, hydrogen. It cannot, indeed, be inferred from the composition of water, as above stated, whether the self-repulsive molecule of hydrogen be double or not; but this may be demonstrated from other compounds into which hydrogen enters. Thus muriatic acid gas is composed of one volume of chlorine and one volume of hydrogen, which unite without any condensation, and form two volumes of muriatic acid gas; now in this case, it is evident that not only the self-repulsive molecule of hydrogen, but also that of the chlorine, must be double at least, like the molecule of oxygen above mentioned; and the same might be shown with respect to the other gaseous bodies.

We have said above that the self-repulsive molecules of oxygen and of hydrogen are *at least* double; but the probability is that they are in reality much more compounded, as the following observations will show. The self-repulsive molecule of water, on entering into combination, is often found to be divided into two or three (perhaps more) parts. Now as we cannot admit the division of an ultimate molecule or *atom*, we must of course conclude that the molecules of oxygen and of hydrogen are much more compounded than as above represented, and must each of them contain at least three component or sub-molecules. Hence the self-repulsive molecules of water will consist of at least nine component sub-molecules (viz. three of oxygen and six of hydrogen) which we may suppose to be associated,—in the first place the hydrogen with the oxygen, *chemically;* and afterwards the three sub-molecules of water with one another *cohesively*, so as to constitute one spheroidal molecule; in a manner that with a little ingenuity it would, perhaps, not be difficult to represent mechanically.*

Precisely the same laws of union may be supposed to prevail among the molecules of bodies themselves, as they actually exist around us. Thus let us take the crystal of oxalic acid as an instance for illustration. This acid is composed, according to the present language of chemists, of two molecules of carbon, and

in the physical properties of bodies, if in a crystalline form; but by no other known means. Do not some of the phenomena of *Isomerism*, that is to say, the property which the same body occasionally possesses of assuming different forms, depend upon these changes?

* When bodies, as, for example, water, are subjected to intense degrees of heat, it is not improbable that in many instances the self-repulsive molecules are more or less separated into their constituent sub-molecules; in which case of course the bodies may be supposed to exhibit altogether different elastic powers and laws of expansion.

three of oxygen, which by combining, form the acid; while, to complete the compound molecule, and to adapt it for crystallization, three molecules of water are required to be somehow associated with each of the molecules of the acid. Now in this case, we suppose, that the two molecules of carbon (each of which is perhaps already made up of several sub-molecules) are associated together into one symmetrical super-molecule; that the three molecules of oxygen are arranged in a similar manner, and then associated *chemically* with the super-molecule of carbon, and thus form by their union a molecule of oxalic acid; finally, that the three molecules of water are united into one super-molecule, which combines *chemically* with the molecule of oxalic acid, and thus completes the molecule of the acid as it actually exists in the crystalline form.

Such are the views we have been induced to take of the nature of chemical combination, and whether right or wrong, they have the merit of being exceedingly simple and consistent with themselves throughout, which can hardly be said of any others with which we are acquainted. Indeed much reflection upon the subject, for many years past, has satisfied us that chemical combinations can be rationally explained only in some such manner as we have supposed. Any lengthened argument, however, upon the laws of chemical combination here, would be quite out of place; we shall therefore confine ourselves to the following observations.

1. The above view of the molecular constitution of bodies naturally suggests the important question: do the sub-molecules, which we suppose to unite together cohesively and form the self-repulsive molecule, of oxygen and hydrogen for instance, possess the same properties as those of oxygen and hydrogen, or do they possess different properties? This question, in most instances, cannot, in the present state of our knowledge, be satisfactorily answered; though there is every reason to believe that the properties both of the sub-molecule and of the super-molecule generally differ from those of the molecule itself, but that the differences are rather of a specific than of a generic character.* Thus chemists have shown that different volumes of the same gaseous body, termed carburetted hydrogen, combine together and form various compounds: we have, for example, a gas, one volume

* What we term the *sensible* properties of bodies are, of course, in all instances, the result of a great number of molecules acting together at the same time; hence below a certain point, mere difference of numbers may be supposed to produce a change in sensible properties, not only in degree, but in kind: of the sensible properties of a single molecule we can form no conception.

of which contains two volumes of carburetted hydrogen ; another, one volume of which contains three, and another four, of the same gaseous body. Now the sensible properties of all these compounds, though resembling each other in some respects, are yet specifically different; and as they are all composed of the same gaseous body in different proportions, these differences must be considered rather as the result of cohesive than of chemical union. Thus the supposition, that both the sub-molecules and the super-molecules of bodies may possess properties different from one another and from the standard molecule, is rendered exceedingly probable by the above facts ; and if our space admitted, it would not perhaps be difficult to bring forward other facts of the same kind. This however, would be foreign to our purpose ; and we shall only remark, that a great many curious circumstances, at present but very imperfectly understood, evidently appear to be referrible to a similar principle.

2. Although we have thus rendered it exceedingly probable that the molecules of bodies considered at present as elementary, are immediately compounded of many others more or less resembling them; yet it is obvious that there must be a point at which these and other elements exist in a primary or ultimate form, and beyond which, if they can be supposed to be subdivided, they must become something altogether different. In this respect, therefore, the views we have advanced accord generally with those at present entertained ; and the only point in which they differ, is in supposing that the self-repulsive molecule, as it exists in the gaseous form, does not represent the ultimate molecule, but is composed of many of them. With respect to the nature of the ultimate sub-molecules of those bodies which we consider at present as elements, as, for instance, of oxygen, they may naturally be supposed to possess the most intense properties or polarities. Indeed such sub-molecules may be imagined to resemble in some degree the imponderable matters, heat, &c., not only by their extreme tenuity, but in other characters also; and this very intensity of property and character may be reasonably considered as one, if not the principal reason, why they are incapable of existing in a detached form. Lastly, are not these ultimate and refined forms of matter extensively employed in many of the operations of nature, and particularly in many of the processes of organization?

3. By supposing that these laws of combination are not confined to elementary bodies, but extend to all others throughout nature; and that bodies, however complicated they may be, always combine with reference to their volume in the gaseous state, and always act as simple molecules; we are enabled in some degree to explain that endless variety of property and condition

which we see around us. For no sooner is a new compound molecule formed by an assemblage of similar molecules, than it may be supposed to be capable of combining with other molecules *chemically*, and of thus entering into a long and novel series of combinations; while these combinations again in their turn may be imagined to lead to others, and so on, till the variety becomes extreme. Indeed were not such combinations limited by the very nature of things themselves, no two substances would probably possess the same properties. As it is, most of these compounds are incapable of separate existence; thus the compound supermolecules of water in the crystal of oxalic acid before referred to, are incapable of separate existence: if they could exist separately, would they assume the form of water?

4. It would not be difficult, though perhaps not very safe or prudent in the present state of our knowledge, to speculate on the crystalline forms assumed by different bodies, with reference to the principles we have advanced. We shall therefore not touch upon this part of the subject, further than by observing that the cohesive force, though supposed to possess some peculiarity as existing *among the molecules of different bodies*, is nevertheless essentially but of *one* kind. When therefore the molecules of different bodies are of the same size (or rather of the same weight,) they may be naturally supposed capable of associating themselves into the same form; and if they happen to be mixed together, they may even enter indiscriminately into the same crystal. Hence arises what has been termed the *isomorphism* of bodies; while if there be a near approximation, but not an exact coincidence in the above relations, they may upon the same principles be supposed to give origin to *plesiomorphism*, that is to say, to a near approach to a similarity of form.

5. With respect to the nature of the circumstances which determine the peculiar characters and modes of existence of bodies we know very little. We are almost equally ignorant also of the nature of the causes which determine the cohesion of the molecules of bodies into the crystalline form. A variety of arguments might, however, be brought forward which appear to show that the size and shape of the molecules have a great deal to do with crystallization; certainly, at least, the molecules must be supposed to have a size and shape somehow or other adapted for the modes in which they are arranged, otherwise they could not be capable of such an arrangement. The cause of this similarity of size and shape is unknown, but it most probably depends upon the *similarity of weight* (*Isobarism*) of the molecule; that is to say, upon the *relation or identity of the absolute quantity of matter which the molecule contains;* which relation, as far as we can perceive, is

not only the sole circumstance common to the molecules of different bodies, but that which of all others is the most likely to produce identity in the size and shape of these molecules.

6. When the molecules of bodies in solution do not happen to possess the requisite size and shape for cohesion, there is from the phenomena every reason to believe, that they occasionally possess the power, as it were, of making up the necessary form, by attaching to themselves the molecules of other bodies. Now, bodies so attached may be considered as acting a sort of complementary part; that is to say, they may be supposed to *complete* the figure or size of the molecule, so as to adapt it for combining in a certain manner. Thus the water of crystallization (and perhaps occasionally other matters) appears in the greater number of instances to perform an office of this kind, and to be in fact strictly complementary to that particular figure and size of the molecules, which may be supposed to be requisite for enabling them, not only to combine the more readily with each other, but at the same time, to form a symmetrical solid or *crystal*.*

One or two other circumstances connected with this part of our subject will be better understood after we have considered a little more in detail, the combinations of bodies with reference to their *weights*, and the absolute quantity of matter which they contain. To this most interesting inquiry, therefore, we shall in the next place proceed, confining ourselves, however, as before, principally to the elements of water, hydrogen and oxygen.

It has been found by experiment that the same volumes of different bodies in the gaseous state have very different weights. Thus for instance a volume of oxygen weighs sixteen times as much as the same volume of hydrogen. Hence as the number of self-repulsive molecules in each of these gases is presumed to be the same, the weight of the self-repulsive molecule of oxygen must of course be sixteen times greater than that of hydrogen; and GENERALLY, *the weights of the self-repulsive molecules of all bodies will be as the specific gravities of these bodies in the gaseous state, or will bear certain simple relations to these specific gravities*. This relation in *weight* among the molecules of

* There is every reason to believe that one variety of isomorphism is effected on the principles here stated; and that the molecules of *different* substances, by attracting to themselves *different* quantities of water, or of other matters, may ultimately make up compound molecules similar to those of the bodies with which they may happen to be mixed, and may thus enter indiscriminately with these bodies into the crystalline form. Such a state of things is calculated to baffle the mere chemist, however expert; though it is probable, that if carefully examined and understood, an intermixture of this kind might be detected by the optical properties of the crystal.

bodies constitutes the basis of what is called the *Atomic theory*, proposed, some years ago by Dr. Dalton, who established the most important fact, that bodies do not, as formerly supposed, combine at random, but in definite proportions by weight; and if the preceding doctrines be well founded, it is evident they cannot combine otherwise.* As however water is composed of one volume of oxygen united with *two* volumes of hydrogen, the relative weights of the hydrogen and oxygen in water will be, not as 1 to 16, but as 1 to 8 only; while the weight of the self-repulsive molecule of steam will be 9. Hence, as one of the other of the elements of water is usually made the basis of the atomic numbers, this difference between the volumes and the combining weights of its elements has produced considerable confusion, and has given rise to much needless discussion. As a mere matter of convenience it is certainly preferable to consider the two volumes of hydrogen as one *atom*, (to use the language of Dr. Dalton), in which case oxygen will be 8, and water 9; but a strictly philosophical arrangement, supposing the principles we have advanced be well founded, would require that *the volume in all instances should be made the molecular unit;* in which case, the relative weights of the self-repulsive molecules of hydrogen and oxygen, as above mentioned, will be as 1 to 16.

In this country two volumes of hydrogen, as we have said, are usually considered as *one atom*, or unity, in which case oxygen is 8; but some have chosen instead of hydrogen, to make oxygen unity or 10, in which case hydrogen of course will be the one-eighth of 1 or of 10, that is to say, .125 or 1.25; and water, instead of 9, will be 1.125 or 11.25. It matters not which of these series of numbers, or whether any other be employed, so that the same relative proportions be observed among them; but the first series is that most generally adopted, and is upon the whole the most convenient. In the above manner the *atomic weights*, as they are termed, of all bodies capable of assuming the gaseous form can be easily obtained; but in those bodies that do not assume the gaseous form, in their simple state, but in some state of combination only, we are obliged to deduce the weight of the primary molecule from that of the compound. Thus carbon in its elementary state is incapable of assuming the gaseous form; but combined with oxygen it forms carbonic acid gas, one volume of which weighs 22 times as much as our standard two volumes of hydrogen. Now it has been found by other experiments, that of these 22 parts, 16 are oxygen. The remaining 6

* The reader is referred to "An Introduction to the Atomic Theory," recently published by Dr. Daubeny, Professor of Chemistry, at Oxford, for an interesting and able inquiry into the principles of this theory.

must therefore be carbon ; and accordingly 6 is the number upon our scale representing carbon, and the proportion, with reference to which, this body always enters into composition. In the case of bodies, as for instance, lime, which are incapable of assuming a gaseous form either alone or in combination, we are obliged to trust solely to analysis ; thus common marble or carbonate of lime, as it is termed by chemists, is found to be composed of 22 parts of carbonic acid, and 28 parts of lime ; 28 therefore represents upon our scale the atomic weight of lime, and so of all others.

It may be observed that we have spoken as if the atomic weights of bodies were related to one another by multiple ; that is to say, were all multiples of some common unit. Now this opinion has been maintained by some, while it has been denied by others ; who admitting that multiples in weight are necessary to the union of the *same* body, both *chemically* and *cohesively*, will not admit that they are necessary to the union of *different* bodies. The matter is one that in the present imperfect state of chemistry can hardly be determined by experiment; for what with the difficulty, or rather impossibility, of procuring bodies in a perfectly isolated form, and the unavoidable imperfections of all chemical processes, we can scarcely hope to arrive within the necessary limits of precision. If the above views of molecular relations however, be well founded, it seems almost impossible to arrive at any other conclusion, than that the combining weights of all bodies are intimately related by multiple ; though to enter further upon the subject here would be quite foreign to our present purpose.*

Lastly, it may be remarked that the numbers at present con-

* For the sake of those who are interested in such matters, one or two of the leading arguments may be briefly stated. We have rendered it probable that when two or more molecules of the same body combine *cohesively*, they form a compound, which though having properties in some degree allied to those of the original molecule, nevertheless usually possesses a specific difference, (that is to say, the *chemical* polarities of the compound molecule as modified by the union, will be different from those of the simple molecule). But a body possessing a *specific difference* may be supposed to be a *new* body, and thus capable of combining in future, *not* cohesively, but *chemically* with our original molecule. Now in such a case it is evident that the weight of the original molecule and that of the new compound molecule *must* have a certain relation to one another by multiple. If our space admitted, it would not, we believe, be difficult to point out instances of such combination among chemical phenomena ; but we shall merely observe, that many of the substances at present considered as elementary, appear to be constituted upon the above principles from some common molecule of a still more elementary character. Moreover this law seems to hold universally throughout nature ; and those substances related to the same molecule, in general constitute a natural group or family, having certain properties in common.

ventionally employed by chemists, to represent what have been called the *atomic weights* of bodies, are so convenient that they will not readily, nor indeed ought lightly, to be set aside ; though there is reason to believe that many of them require revision, and are destined to undergo material alterations, even as the subject is at present understood. If the views however which we have advanced be correct, these numbers certainly do not represent nature ; for as we have already stated, a strictly philosophical arrangement can be rationally founded only upon the volumes of bodies in the gaseous state, in which state some common volume in all instances should be considered as the molecular unity. Now, as in most instances, this molecular unity seems capable of subdivision, of course the number made to represent it can hardly ever be supposed to be a *prime* number. Hence, as combining molecules of bodies exist both below and above the molecular unity, they may often (perhaps always) be represented by a series. Thus suppose 9 to represent the molecular unity or volume of water, and that this be subdivided into three (which it is at least, and probably into a much greater number) ; the molecular combinations of water may be represented by the series, 3, 6, 9, 12, 15, 18, &c. We mean to say, the molecules of water as they actually enter into a combination in different bodies, may be supposed to be represented by these numbers ; while, by way of distinguishing the different molecules, those below 9, may be designated generally *sub*-molecules, and those above *super*-molecules ; and the molecular unity itself may be simply called the *molecule*, or in the gaseous state the *self-repulsive molecule ;* distinctions, which for the sake of convenience, we have adhered to throughout these remarks, and which we have thought it thus necessary to explain.*

Section III.

General Remarks upon Chemical Compounds.

The number of chemical compounds is so great that an attempt to enumerate them here would be quite out of place ; we shall therefore content ourselves with stating, as briefly as possible, the general principles upon which these compounds are formed.

We have already pointed out many of the more remarkable compounds, when speaking of simple bodies ; and in subsequent parts of this volume we shall have occasion to allude to others. In

* The above terms are to be considered as a temporary expedient only. If these views be established it will not perhaps be difficult to devise hereafter both a notation and a nomenclature founded upon them. At present such an attempt would be ridiculous.

speaking of simple bodies we showed that by far the greater number of them occur in the metallic state, and are incapable of existence upon the surface of our globe, on account of the tendency they possess to enter into combination, particularly with oxygen. It would seem also, from the intensity of the properties and the general incompatibility of the simple bodies with the present order of things, that their compounds, rather than themselves, were the objects the Author of nature had in view. Hence perhaps we are more immediately interested in the character of the compounds than in that of the elements themselves. Of the general nature of these compounds, the following observations, taken chiefly from Dr. Thomson's work on chemistry, will serve to convey some idea to the general reader.

The COMPOUNDS which bodies form with one another are either PRIMARY OR SECONDARY. By PRIMARY COMPOUNDS are usually understood those which are formed by the combination of two or more simple bodies with each other; while by SECONDARY COMPOUNDS are meant the compounds formed by the union of the primary compounds with each other.

The PRIMARY COMPOUNDS naturally divide themselves into three grand classes, viz. *acids*, *alkalies* or *bases*, and *neutrals;* on each of which we shall make a few remarks.

Of Acids. Formerly it was considered as requisite that bodies, in order to belong to the class of acids, should have a *sour* taste, should be soluble in water, and should have the property of reddening vegetable blue colours; and these properties do indeed belong to some of the most common and powerful acids. But there are various acids which have no taste, which are not soluble in water, and some which are incapable of altering the colour of the most delicate vegetable blues; hence the term *acid*, as at present employed by chemists, is understood to denote a substance which has the property of combining with, and neutralizing, alkalies or bases. The celebrated Lavoisier endeavoured to prove that oxygen constitutes an essential ingredient of all the acids; but later observations have shown that not only oxygen, but the analogous principles, chlorine, bromine, iodine, and fluorine, are also capable of forming acids by uniting with several of the acidifiable bases. Still more recently, certain compounds of cyanogen, (a primary compound of carbon and azote), of sulphur, of selenium, and of tellurium with the acidifiable bases, have been ranked among the acids; so that the acids at present known may be divided into nine classes, viz., *oxygen acids*, *chlorine acids*, *bromine acids*, *iodine acids*, *fluorine acids*, *cyanogen acids*, *sulphur acids*, *selenium acids*, and *tellurium acids.*

The *oxygen acids* are more numerous and better understood

in general than the other classes; they may be subdivided into two kinds; those with a single base; and those with a compound base. The acids with a single base amount to between thirty and forty, and include most of the best known and most important of those used in chemical processes and in the arts; such as *carbonic acid*, *sulphuric acid*, *phosphoric acid*, *nitric acid*, &c. The oxygen acids with a compound base are chiefly derived from the vegetable or animal kingdoms; they are still more numerous than those with a single base, the number at present known amounting to upwards of sixty; as instances may be mentioned the *tartaric acid*, the *citric acid*, the *malic acid*, the *lithic acid*, &c.

The *chlorine acids* are perhaps as numerous as those containing oxygen, but they have been much less studied, and are, consequently, much less understood. One of the most familiarly known belonging to this class is the *muriatic* or *hydrochloric acid*, which is composed of chlorine, united with hydrogen: and here may be noticed a remarkable circumstance, that not only chlorine, but all the other allied principles, when they combine with hydrogen, form powerful *acids;* while the compound of oxygen with hydrogen, as we have formerly noticed, is *water*, a substance altogether dissimilar. Such is the wonderful and inexplicable nature of chemical combinations!

The *acids* containing *bromine*, *iodine*, and *fluorine*, are still less satisfactorily known than those containing chlorine. As just observed, the acids formed by these different principles with hydrogen, viz. the *hydrobromic*, the *hydriodic* and the *hydrofluoric acids*, possess the most decided properties and are best understood.

The *cyanogen acids* are numerous and important, as most of them are poisonous; thus the compound of cyanogen and hydrogen (analogous to those above mentioned) is the *hydrocyanic*, or *prussic acid*, one of the most virulent poisons in nature, and instantly fatal to organic life in every form.

Of the remaining acids, the *sulphur acids*, the *selenium acids*, and the *tellurium acids*, we know very little. Those with which we are at present best acquainted are analogous to the preceding acids, and are formed by the union of the different principles with hydrogen. These acids were formerly known under the names of *sulphuretted*, *seleniated*, and *telluretted hydrogen;* but some chemists have now given them new names conformably to the above nomenclature.

Of alkalies and bases. Bodies of this class, are, like the acids, composed of different elementary principles, and particularly of certain metals, combined with oxygen, chlorine, &c., but usually in less proportions than in the acids. Hence the alkaline bases are as numerous as the acids, and may be divided in a similar manner into *oxygen alkalies*, *chlorine alkalies*, &c. Of

these the *oxygen alkalies* are by far the best known and most important, and they may, like the oxygen acids, be subdivided into two kinds, viz. those with a single base, and those with a compound base. The alkalies with a single base include all the well known common alkaline bodies, *potash*, *soda*, *lime*, *baryta*, &c.; while the alkalies with a compound base are chiefly from the vegetable kingdom, and comprehend the newly discovered alkaline matters, so successfully introduced into medicine; such as *quinine*, from bark, *morphine*, from opium, &c., the composition of which at present is not well understood. *Ammonia* or the *volatile alkali*, may perhaps be referred to this class of alkalies; though its composition as consisting of hydrogen and azote only, without oxygen, may be considered as constituting an exception or anomaly.

The other *alkaline* bodies into which *chlorine*, *iodine*, &c., enter, are very little known, and some perhaps may be even inclined to doubt their existence.

Of neutral compounds. These are arranged by Dr. Thomson, under seven heads, the mere naming of which will probably be all that is required, to convey to the general reader a sufficient notion of their nature. They are *water*, *spirits* or *alcohol*, *ether*, *ethal*, (a peculiar oily substance obtained from spermaceti) *volatile oils*, *fixed oils*, and *bitumens*.

Such is a summary of the PRIMARY COMPOUNDS and of the principles upon which they have been most recently arranged. We come now to consider briefly

The SECONDARY COMPOUNDS, or those formed by the union of the primary compounds. As the neutral primary compounds (if we except water) enter into few combinations, it is obvious that the SECONDARY COMPOUNDS must consist chiefly of substances formed by the union of the other two general classes of bodies, namely, of *acids* and *alkalies*. These SECONDARY COMPOUNDS are usually denominated SALTS; they constitute a very numerous and most important class of bodies: and as resulting from the mutual union and saturation of all the different principles capable of combining with each other, they of course are more abundant than any other bodies; indeed, the surface of our globe, may in a great measure, be considered as made up of them. The term *salt* was originally confined to common salt; but by a singular fate, this body, as being composed of chlorine and sodium only, is now excluded from the class of salts: salts being, as we have just said, considered by chemists, to be formed by the union of acids and alkalies only. As there are nine classes of acids, of course there must be as many classes of salts; of these, the *oxygen acid salts* are by far the best known and the most important; and, indeed, this class includes the greater number of those salts employed by chemists or in the arts. If these salts

be arranged according to their bases, which perhaps upon the whole, in the present state of our knowledge, is the best mode of arranging them, they will be found to constitute upwards of fifty genera; and if we consider that each of these genera includes, in most cases, a great number of species, we may form some idea of the wonderful variety of bodies existing in nature, and with the properties of which the chemist is required to be conversant. Familiar instances of the oxygen acid salts are, *nitre*, *common chalk*, *gypsum*; various metallic salts, as the *white*, *green*, and *blue vitriols*, &c. &c.

Of the *chlorine* and the *other classes of salts* very little is known, and this little is chiefly confined to the salts composed of these principles and of hydrogen. The hydrochloric or muriatic acid combines with ammonia, and forms the well-known compound *sal-ammoniac*, a salt supposed to be a true *hydrochlorate* or *muriate*. But this is the only instance known; and in all other analogous instances, the hydrogen of the hydrochloric acid and the oxygen of the base, unite to form water, which is separated or separable; and thus the chlorine and the metallic base are left in union by themselves in the state of a *chloride*. This is the case, for instance, with *common salt*; which, as we before said, is in reality a *chloride* of *sodium*, that is to say, a simple compound of chlorine and the metal sodium. Similar remarks appear to be applicable to the other analogous compounds. It must be confessed, however, that our knowledge with respect to all these matters is at present in a very unsatisfactory state, and is probably destined at no very distant time to undergo a complete revolution.

Section IV.

Recapitulation. General Reflections on the Subjects treated of in the preceding Chapters.

The subjects considered in the present chapter may be viewed as a continuation of what has engaged our attention in those that have preceded; and the principal circumstances detailed may be thus recapitulated.

1. All perfectly gaseous bodies combine with reference to their volume; that is to say, any volume or bulk of a gas always combines with an equal volume or bulk of the same or of another gas; or with a volume having some simple relation to its own volume, as half, or twice as much; &c. and not with any intervening fractional part of a volume.

2. The same volume of different gaseous bodies has very

different *weights:* hence on the supposition formerly advanced, that all perfectly gaseous bodies under the same pressure and temperature contain an equal number of self-repulsive molecules, the molecules of different gaseous bodies must also have different weights; which weights will be as the specific gravities of the gases, and may be represented by numbers proportional to these specific gravities.

3. From the above relation between the volumes and the weights of bodies in the gaseous state, it follows, that *all bodies must combine with reference to their weights;* that is to say, that the same weight of the same body (or half or twice as much, &c.) must always combine with the same weight (or half or twice as much, &c.) not only of the same, but of every other body.

4. The numbers representing the relations among the specific gravities of bodies in the gaseous state, are called the *molecular* or *atomic weights* of the different bodies.

Such is the foundation of what is usually called the *Atomic Theory;* the principles of which are generally admitted as regulating chemical combinations.

We shall now conclude the present Treatise on chemistry with a few remarks more especially relating to the object of these volumes. And here it may be observed, once for all, that throughout the preceding pages, as well as in what follows, we have endeavoured to state each argument as distinctly as possible, without encumbering it too much with details—in short, to illustrate principles rather than to enumerate particulars. When the principles of a cumulative argument are understood, the details are readily supplied by the reader.

First. On taking a general and collective review of the facts brought forward in the preceding chapters, the circumstances calculated to strike our attention in the first place, are the wonderful coincidence between the priority of existence, and the universal prevalence of the primordial agents and elements of nature, on the one hand; and on the other, the beautiful adaptation of the agents and elements of a later and more subordinate character to these primordial principles; so that when the whole are taken together they constitute one harmonious and connected series, in which all the various parts are mutually adapted and dependent. In the following chapters we shall have occasion to notice many of the more important of these subordinate arrangements; at present we shall chiefly confine ourselves to a general review of what has been already stated.

We are told by the inspired historian that after matter had been created and endowed with motion, the next Almighty fiat was "let there be light;" and if we suppose this fiat, to have included the other imponderable forms of matter, heat, &c., how

entirely do the whole phenomena of nature accord with the sacred narrative? Light, and probably its attendant heat, are the most generally diffused and universal of all the subordinate agencies; so much so, that they are not confined to our globe or even system, but extend throughout the universe. Their laws and influences, therefore, seem to be as general and as necessary to the present order of things, as those of gravitation itself. The priority of existence also of light and of heat is self-evident; for until they existed, nothing else, as we are acquainted with things, could have had existence. Now all subsequent creations have been made with the most exact regard to the influences of these prior agencies. The globe, for example, which we inhabit, is at a certain distance from the sun, the great centre of our system and of light and of heat; and where of course, according to the laws which light and heat obey, they must act with a certain intensity. Hence it was necessary that the materials of this globe should have a certain degree of fixity, otherwise they could not exist. If indeed there had been no ulterior views, with respect to the destination of this globe; all that would have been requisite, would have been to have made it sufficiently firm to move through space; and for this purpose the more homogeneous and compact its composition had been the better. But what are the facts? Our globe, though stable, so far from being homogeneous, is composed of a variety of substances all differing from each other in their properties; some being solid, some fluid, some aeriform under the common circumstances in which they have been placed, and all beautifully adapted, both by their physical and chemical properties, to the purposes they fulfil in nature; and what is more, to the purposes they were *designed* to fulfil in nature; for on no other supposition would their properties be intelligible.

Thus water, *within very narrow limits of temperature*, is a solid, or a liquid, or a gas; and yet these *very narrow limits of temperature*, neither more nor less, are precisely those which exist upon the surface of our globe; where they are the natural and necessary results of its situation in the universe, and of the general laws which govern the distribution of light and heat. Had the properties of this body been other than what they are, or had the general temperature of our globe been different, water would have existed altogether in the solid or in the gaseous state, and its most important properties would have been unknown. Hence it seems almost impossible to arrive at any other conclusion, than that the temperature of the earth, and the properties of the water on its surface, have been mutually adjusted to each other. And further, since the temperature of the earth, as just stated, is the natural result of the general laws which govern the distribution of heat and of light; the inference must be, that the properties of the water,

as the subordinate and later principle, have, at an after period, been adjusted to the prior temperature of the earth.

If we do not admit of this adjustment, we must suppose that the whole has been the result of chance, or of some other unintelligent principle; and if water had been the only principle in which such adaptations were apparent, the supposition of chance might, perhaps, be received; at least it would have been difficult to prove the contrary. But when we see similar happy adjustments in every object around us,—in the different elements of the air we breathe, the soil we tread upon, the rocks in all their varieties, composing the solid crust of our globe, not one of which could have been more happily contrived for the purposes they fulfil, nor indeed be scarcely conceived to exist otherwise than what they are, without destruction to the whole of the present arrangements—when we see all these things, and duly reflect upon them, it becomes absolutely impossible to admit that so much happy adjustment, so much apparent intelligence, so much, in short, of what the veriest sceptic under other circumstances would have allowed to have been evidences of design, can be evidences of any thing else than design, or have resulted from any unintelligent cause whatever. Hence we are driven irresistibly to the only rational conclusions which the premises appear to admit of, viz., that all these happy adjustments and adaptations which we see in nature, are really and truly what they appear to be,—so many evidences of design; and, consequently, that the whole have sprung from the will of an intelligent and omnipotent Creator.

The above inferences are deducible from the plain and obvious arrangements of nature, which every one can readily understand: but when speaking of elementary bodies we remarked, that in a variety of instances, their object and use were unknown to us; and before we quit this part of the subject, it may not be out of place to consider briefly these difficult points.

When we see adjustments so wonderful, and such wisdom displayed in those parts of creation which are intelligible to us, we cannot imagine that the Being who made them all would act otherwise than with wisdom. Hence what we do not understand, or what may appear incongruous to us, we naturally and properly refer to our own ignorance. The phenomena of chemistry are so extraordinary and often so unexpected, that little in general can be predicated of them, beyond what is actually known. The most experienced chemist, therefore, as compared with the Great Chemist of nature, is immeasurably deficient; and can only contemplate His wonderful operations with astonishment and awe, and own them unapproachable. Who then can tell what design is latent under *apparent* incongruities? What elaborate contrivances and adaptations may have been requisite to have produced

water or carbon, or any other essential principle, out of the materials and in conformity to the laws, by means of which the Great Author of nature chose to operate? Who can tell that the minor evil may not have been essential to the existence of the greater good? That the poisonous metals, for instance, are not, as it were, the refuse of the great chemical processes by which the more important and essential principles of nature have been eliminated? That these poisonous principles have not been left with such subdued properties as scarcely to interfere with His great design,—not because they could not have been prevented—not because they could not have been removed—but on purpose and designedly to display His power?

Secondly. If we pursue the subject a step further, and inquire into the means by which all the beautiful adaptations we have been considering are effected, we shall find that they principally depend upon a certain due adjustment to each other of the *qualities* and *quantities* of the different substances, and more especially of the different elementary principles, of which our globe is composed. These adjustments are so universal and so varied in their character, that to enumerate them all, would be little else than to enumerate all the objects in nature; we shall therefore content ourselves with a few of the most familiar of each kind.

In the first place, with respect to the adjustment of *quality*. Let us consider for a moment and by way of illustration, what would happen if the qualities of water or of air were to undergo a change: were, for example, the important fluid water to become sour or sweet, or heavier or lighter, or indeed anything but what it is; or were the air of the atmosphere to acquire odour or colour, or to become opaque: by either of such changes, slight as they appear, the whole of the present economy of nature would be deranged. Again, if the qualities of the acid existing in the common salt of the ocean were to become so modified as to quit the alkali with which it is at present associated, and to combine with the limestone composing our rocks; while the carbonic acid, thus set free, was diffused through the atmosphere: in such a case a large part of the solid crust of our globe would rapidly disappear and become dissolved in the waters of the ocean, which would thus be totally unfitted for their present purposes; while the liberated carbonic acid would instantly prove fatal to animal life. Such would be the consequences of these trifling changes in the qualities of a few substances only; nor is it possible scarcely to conceive any other change that would not be attended with similar results.

In the next place, the importance of the adjustments of *quantity* is equally striking. Let us, for instance, conceive what would happen from the simple inversion of the quantities of dry

land and of sea as they now exist: in such a case there would not be enough of water to preserve the surface of the land in a moist state, and the greater part would be in the situation of the deserts of Africa, and totally unfit for the habitation of organized beings. When speaking of the elements of water, we alluded to the happy adjustment of the quantities of oxygen and hydrogen in the world; and to the consequences that would have ensued if hydrogen, instead of oxygen, had predominated. The same remarks apply to almost every other element; for example, had the proportions of chlorine, and of the soda in common salt; or of the carbonic acid, and of the lime in our marbles, been anything but what they are, the one or the other of the ingredients must have been in excess, and the present order of things could never have existed. Again, were gold suddenly to become as abundant as iron, and iron as rare as gold; were the carbon existing in the present useful form of fossil coals, to assume the crystallized form and become diamonds; the whole order of nature would be subverted, and the whole of the present arrangements be involved in ruin. Those who deny the argument of design, of course, consider such suppositions as these absurd; and if carried too far, they doubtless, under any circumstances, lose much of their effect; but admitting the argument of design, the judicious application of such suppositions is well calculated to place the advantages and effects of certain arrangements in a more striking point of view than can be obtained by any other means. More especially, such suppositions, by showing the wonderful adaptations of subsequent creations to prior existences, are admirably calculated to illustrate the fitness, and consequently the *apparent* design displayed in the formation of these prior existences; and thus to show that they must have been created with reference to ulterior purposes.

The argument of prior arrangements and the subsequent adaptation to these arrangements of other creations is one of such interest, and its consequences are so important, that perhaps it may not be deemed irrelevant if, for further illustration, we recapitulate the principal points in a condensed form. For this purpose we shall select the obvious and familiar relation between water and air, and plants and animals.

The prior existence of water and air as compared with that of plants and animals, is established by the fact, that water and air *can* exist without plants and animals, but that plants and animals *cannot* exist without water and air. Hence as water and air must have existed with all their present properties before plants and animals were created, the question naturally arises, how water and air came to be endowed with their present properties? *We* suppose that water and air were created with their present properties, with reference to the future existence of plants and

animals; and on this supposition the whole becomes intelligible. Further, that this is the true explanation, and that water and air have not obtained their present properties by chance or accident is rendered still more probable by the following considerations. We have said that water and air can exist without plants and animals; now as far as we know, water and air might have existed *for ever* without plants and animals; at least the contrary cannot be proved or even rendered probable. Moreover, plants and animals, as involving new principles of a higher order (those of life), never could by any law of nature, necessary or probable, have resulted from an inferior agency. Hence there is no necessary relation of cause and effect between the prior existence of water and air, and the subsequent existence of plants and animals; as some seem to have supposed. Hence too it follows irresistibly, that plants and animals have been created, and their properties adapted to those of water and of air at some subsequent period, and by some external and superior agent. But the agent that could thus create plants and animals, could surely have created the water and air likewise; nay, *must* have done so; for, as the prior and subsequent creations taken together, evidently form but different parts of one and the same general design, the whole design must have been the work of one and the same intelligent Agent.

It yet remains to draw the attention of the reader to another circumstance connected with these adjustments in quality and quantity, viz. the *double* adjustment. Of the causes of the qualities of bodies we know but little, and that little is founded solely on experience. We see that these qualities are admirably fitted for their apparent purposes, and hence (as they might have been different), we arrive at the probable conclusion that they have been so fitted by design. The collocation of quantities and numbers, exactly where they have been required, adds much to the probability of this conclusion; as such a collocation could hardly have been other than the act of an intelligent Being. But the *double adjustment in quality and quantity of the same thing at the same time*, adds almost infinitely to the weight of evidence; and indeed furnishes a proof in favour of design and of its consequences, which amounts to all but actual demonstration.

Thirdly. There is another point of view in which we may consider what has been stated, and by which we shall at the same time be brought a step nearer to the existing order of things. Amidst all that endless diversity of property, and all the changes constantly going on in the world around us, we cannot avoid being struck with the general tendency of the whole to a *state of repose* or *equilibrium*. Moreover, this tendency to equilibrium is not confined to the ponderable elements, but prevails also in the same

striking degree among the imponderable agencies, heat and light; which as we have seen, cannot be any where long retained in a state of excess, on account of their natural disposition to acquire a certain state of equilibrium; depending generally upon the place of the earth in the solar system. Now, the formation of this state of equilibrium, and its preservation, may be considered as the results of those wonderful adjustments among the qualities and quantities of bodies above alluded to—the qualities being such as to neutralize each other's activity, while the quantities are so apportioned as to leave one or two only predominant.

The preceding is a general view of the subject. But it is to be observed, that the state of equilibrium here described is not absolutely *fixed;* as such an unyielding condition would be not less incompatible with the present order of things than a condition of unlimited change. The whole are so adjusted therefore, that slight deviations, or oscillations about the neutral point of rest or equilibrium, take place, and are even necessary, as the world is at present constituted; though these changes are bounded within very narrow limits, and greater deviations would instantly prove fatal to the whole. If we inquire into the principles upon which these slight deviations take place and are regulated, we shall find still further reason to admire the wonderful arrangements displayed. When speaking of the elements of water, we observed how much the stability of nature depended upon the proportions of the elements of this fluid; and that one of its elements, oxygen, existed in excess, and in a free state, in the air. Now, it is to the agency of this oxygen in a free state, and to the annual and diurnal motions of the earth, that most of the minor operations going on around us are to be referred. The universal presence and peculiar properties of oxygen are such as to interfere more or less with everything; while the motions of the earth keep everything in a constant state of activity and change. Yet, the general tendency of the whole, as before observed, is towards a state of equilibrium; and the principles upon which this tendency operates, are very intelligible. Thus, all bodies *below* the neutral point of rest, if we may be allowed the expression; that is to say, all bodies of a marked elementary character, have a tendency to combine with each other *synthetically;* while *beyond* the neutral point, bodies have very little tendency to combine further; and if by intention on the part of the operator, or from any other cause, they be so made to combine, when left to their own operations, they speedily revert or oscillate back to the point of equilibrium.

Such are the means by which the state of equilibrium we are considering has been produced, and by which it is still preserved; nor is it possible to reflect upon the subject for a moment with-

out arriving at the conclusion, that this state of equilibrium possesses all the characters of a prior arrangement, to which organized beings have been subsequently adapted. We are thus led, in the next place, to make a few remarks upon the subsequent adaptation of organized beings to the pre-established equilibrium of nature.

The present races of organized beings in all instances are produced only by the process of generation; and if they were annihilated, there are no natural operations going on in the world, which can lead us to believe, that by any law of nature such organized beings could be reproduced. That is to say, we cannot conceive that hydrogen, carbon, oxygen, and azote, with heat and light, &c. from what we know of their properties, would ever be able, of their own accord, so to combine as to form a plant or an animal. Hence, when plants and animals were first produced, it is evident that there must have been a power or agent in operation, which has long since discontinued so to operate; and that this power or agent not only created plants and animals; but at the same time imparted to them a capability of perpetuating their existence, for a period, at least, commensurate with that state of equilibrium in which they have been placed. Now, whether we consider the power or agent who accomplished all these things, to have been the Deity himself operating immediately, which is most probable; or whether we consider with some, that He operated by delegated agencies and laws, the result is the same as far as our argument is concerned; the object of which argument is to show, that the present races of organized beings are somehow or other influenced by the same general laws which appear to regulate inorganic matters. That is to say, organized beings at the present time, are at least as fixed and permanent in their nature, as the state of equilibrium in which they have been placed; and consequently, no new plants or new animals can, as the world now exists, be imagined to be produced without a new and specific act of creation; or at least, without an entire change in the standard of equilibrium.

We have alluded to the commencement of the present order of things, and to a possible state of change in the condition of equilibrium: perhaps it may not be amiss to make a few further remarks upon these points. That the present order of things most certainly has had a beginning; and as certainly will come to an end, we cannot doubt; the questions are, when was this beginning; when will be this end? Of the end of course we can know nothing: the beginning is less obscure; and there are indelible impressions left upon the materials and structure of our globe, which throw no ordinary light upon this question. The consideration of the changes which our earth has undergone, however, belongs to another department: we shall only observe that these

changes appear to be of two distinct orders, which have alternated with one another in succession. The first of these orders of changes seems to have been of a slow and gradual kind, and such as might be supposed to take place during a state of things, more or less like the present, and existing for a considerable period. The changes of the second order, on the contrary, have evidently been violent, sudden, and disruptive, of comparatively short duration, and differing exceedingly in degree and in extent. In general they appear to have operated from within; but whether altogether from internal or from external influences, is unknown to us. Now, it is remarkable that these successive alternations seem each time to have changed the standard of equilibrium; and that during the state of comparative quietude, or the interval of equilibrium between the convulsions, organized beings have existed, adapted to the exigencies of that particular state of equilibrium; and which beings must have been successively created: moreover, the later creations gradually approach to those at present in existence. Hence, the change in the standard of organization seems to have been not only simultaneous with the change in the state of equilibrium; but doth appear to have been progressively raised after each convulsion. Finally, the last general catastrophe of the disruptive order was evidently a deluge.* Such are the conclusions which geologists have deduced from a careful survey of that part of the crust of the earth to which they have access; and these conclusions are of the most important kind. In particular, by demonstrating the existence of successive adaptations to different successive states of equilibrium, they place the argument of design in a new light, and add in no small degree to its force. This part of the subject, however, belongs to the geologist, to whom, for the present, we shall leave it.

Fourthly. The argument of design as connected with the subject of equilibrium above treated of, may be considered yet in another point of view. In this state of equilibrium we have observed that the properties of bodies, as they actually exist around

* If we judge from what we see going on in nature around us, and from the little tendency there appears to be in things at present to combine into new forms, we must be almost led to the conclusion that the developement of new elements, as well as of new agents, is necessary to produce new and specific arrangements. May we not then infer that during those periodic convulsions alluded to in the text, new elements have been developed, or old ones decomposed into others of a higher and more elementary kind; and that in virtue of the general laws in operation, these new elements have subsequently combined to form series of new arrangements? Of course this supposition is intended to apply only to the *means* adopted by the Deity to effect his purpose. The formation and selection of these new elements must in all instances be supposed to result immediately from his will and agency.

us, are all so subdued and passive in their character, that no one predominates over, or excludes the other. Now, when we reflect that almost all these bodies are *compounds*, and when we compare the properties of these compounds with the properties of the elements composing them, it is impossible not to infer, that the properties of the compounds rather than those of the elements, were, at their origin, the objects contemplated. That is to say; in order that the compounds might be perfect, the elements calculated to produce them, were created essentially such as these compounds might require, without reference to the secondary properties of the elements themselves; which were left to be determined as the more general laws of matter might decide. For instance, the properties of hydrogen in water, and of chlorine and sodium in common salt, not being required in the economy of nature, the properties of these elements have not been made compatible with organic existence; and the whole attention (if such a term may be applied to the operations of the Deity) has been directed to the properties of the compounds, water and salt. Thus, on the one hand, where required, we have the most striking adaptation of property; while on the other, where *not* required, this adaptation of property has *not* been attended to: nor is this true of water and salt only, but of almost every other compound in nature. Nay, what is more, the incongruities of the whole system have, with the most consummate skill, been thrown, as it were, among those properties *not* required. Hence, the arrangements of nature viewed in this light, not only exhibit novel evidences, but some of the most striking evidences of design that we possess.

The subject of the incongruous properties of bodies is one of great interest. We have seen that many of the elementary principles are poisonous; and that almost all of them, if liberated from their affinities, and sent abroad in the world, like so many demons let loose, would instantly bring destruction upon the whole fabric. Now, why should such incompatible properties be necessary to the properties of the compounds? Why, for instance, should the incombustible fluid water contain one of the most combustible principles in nature? or the mild and innocuous common salt be composed of two elements, which, in their separate state, would instantly destroy life? Why, do we repeat, are these deleterious properties of the elements necessary to the wholesome condition of the compound? What part do they perform; or what property do they contribute to, or represent? These are questions utterly beyond our comprehension, and are likely always to remain so. That these incompatible properties of the elements, however, do, in some way, contribute to the perfection of the compounds, we cannot doubt; and the only grounds upon which such incompati-

bility seems to admit of explanation is, that it results necessarily from those limitations which the Deity has thought proper to prescribe to his power, and to which he always most rigidly adheres. Moreover, be the reason what it may, it is evident that these arrangements, so immediately calculated to lead to practical difficulties, have been the result of *choice*. For we cannot but believe that an omnipotent Creator, if he had so willed, could have made the elements innocuous, as well as the compounds ; nay, to our limited understanding this would have been the easiest and most natural mode of proceeding. Why then did he choose the apparently more difficult course ? Why, to use the language of Paley, but "that he might let in and thereby exhibit demonstrations of his wisdom." Throughout nature, the exigencies and incongruities necessarily arising from the arrangements we have been considering, have given occasion for the display of the most astonishing wisdom and power. And instead of that jarring and clashing which might have been expected from so many conflicting elements, the qualities and quantities of these elements have, upon the whole, been so wonderfully adjusted to each other, that they neutralize and balance each other's evils ; and the general result has been, that all have finally settled down together into that harmonious state of equilibrium before alluded to, so admirably adapted for the existence of organic life.

Fifthly. We have hitherto confined our attention to general principles and arrangements ; but the commonest chemical process may be made to furnish us with some striking proof of the omnipotence of the great Creator. Let us for example consider what happens in a simple and familiar instance of chemical decomposition ; as when a solution of lunar caustic (nitrate of silver) is added to a solution of common salt. In this case, the chlorine of the salt combines with the silver, and produces a curdy precipitate which falls to the bottom ; while the nitric acid combines with the soda, and forms a soluble salt which remains in solution. Now, we showed in a former chapter that the minutest fragment of matter appreciable by our senses, consists of innumerable molecules. If therefore we suppose a small quantity, as an ounce, of the lunar caustic, and a proportionate quantity of common salt, to be mixed together ; what countless myriads of molecules, in a portion of time literally inappreciable, must have sought out, and combined each with its fellow, in this simple process ! The human mind absolutely recoils from the contemplation of objects so completely beyond its powers ; for the utmost that we can imagine, must fall almost infinitely short of the reality. Were we, for illustration, to conceive every human being at present in existence, to be collected together into one vast array, and to be all dressed exactly alike, and to perform the same military manœuvre at the

same moment; we should be probably as far short of the actual numbers of similar molecules, each manœuvring exactly alike in the above simple experiment, as a single company falls short of our congregated army! Again, to take another familiar illustration, as the working of a common steam engine; we are assured that in this simple operation, there are more self-repulsive molecules of water always constantly engaged, and conspiring to the same end, than there are of quadrupeds in existence upon the whole surface of the globe! The above are designed to illustrate the principles of the argument only: the argument itself, like all the preceding is strictly cumulative, and applies more or less to every operation in nature.

Such is a summary sketch of the wonders developed by chemistry; and what an idea do they convey to us of the wisdom and of the power of Him who contrived and made the whole! Of the *capacity* of that eternal Mind, who while He directs the universe, at the same time takes cognizance and regulates the movements of every individual atom in it! To whom the inmost nature, and end, and object of every part are familiar; and of whose comprehensive designs the whole forms but a single link, the antecedent and the consequent to which are merged alike in infinity!

In the preceding pages we have pointed out a few of those wonderful arrangements, which to common understandings appear to indicate design, and consequently to prove that such arrangements are the works of an intelligent and omnipotent Creator. There are however some minds so obtuse, or so strangely constituted that they either cannot, or will not admit the force of these arguments, and who consequently deny the evidences of design altogether. The consideration of this part of the subject properly belongs to another department, to which the reader is referred for details; we shall therefore confine our observations to a brief recapitulation of the leading objections to design, and offer such answers to them as are more immediately furnished by our own subject.

The objectors to the argument of design may be divided into two classes; those who denying a First Cause, affect to believe that all the beautiful adaptations and arrangements, we see around us, are the result of what they call the "necessary and eternal laws of nature," and who in fact are Atheists, or rather Pantheists, "to whom the laws of nature are as gods;" and those who, without denying a First Cause, contend that design cannot be *proved;* that the arrangements of external nature, as they appear to us are little more than mental delusions; and that things appear congru-

ous and adapted to us, however incongruous they may be in reality, simply because we have nothing else than our own intellects with which to compare them.

To the first class of objectors, we may thus briefly reply. The "laws of nature," or rather our knowledge of them, may be considered as of two kinds; First, laws founded upon *reason* or necessity, the phenomena regulated by which laws we cannot conceive to be otherwise than what they are; and laws founded upon *experience* only, among whose dependant and sequent phenomena we can discover no necessary relation whatever. Now, few, if any, of the "laws of nature" can be *proved* to belong to the first kind; we know for instance, no reason or necessity why hydrogen, carbon, oxygen, and azote *must* combine to form plants and animals; we only know that they *do* so combine, but why and how we know not. Hence, as the Atheist cannot *prove* his "laws of nature" to have a *necessary* existence, he has no right to make the assumption. On the other hand, he cannot prove these laws to be *eternal;* for *experience*, the sole ground upon which his knowledge of them is founded, is decidedly hostile to this supposition, as we have in the next place briefly to show.

In reasoning from cause to effect in matters of experience, two conditions at least are requisite; first the effect must be *possible*, that is to say, must not be opposed in any way to the cause, or to the facts of the argument; and secondly, it must be *probable*, or in other words, the effect must accord and harmonize generally with the accompanying phenomena. But the atheistical doctrine of the "eternal laws of nature" seems to us to violate one, if not both these conditions. In the first place, as to the facts, or *possibility* of the case. We have seen, that a very superficial observation of the world as it exists, and as it obviously has existed within the limits that its history can be traced, is sufficient to show, that its course at all times has been progressive. That is to say, the world itself before arriving at its present condition, has not only undergone a progressive series of different states; but in these different states, *different* "laws of nature" have prevailed. In the second place, putting the previous history of the world out of the question, and judging solely from what we see around us, it appears *improbable* in the highest degree, that the present variable and *finite* order of things, should constitute a term or link of an uniform and *infinite* progression. The notion therefore that the "laws of nature" have existed as they now exist from eternity, if not actually *impossible*, is so exceedingly *improbable*, that it cannot be admitted for a moment. Hence as these laws cannot be proved to have a necessary existence, or to have existed from eternity as they now are; it becomes more than probable that they

have had a beginning; and thus the inference of a pre-existent Law-maker, and all its consequences are at once inevitable.

We come now to consider the second class of objections to the argument of design; those namely, which are founded on the grounds that design cannot be *proved;* and that what we call design is little more than mental delusion. We admit at once that everything we know of external nature we know from *experience* only; and consequently we admit that what we call design in external nature is only *very probably* design; that is to say, cannot be *proved* to be design by any argument founded on *reason or necessity*. But having made this admission, we assert upon the self-same grounds, that our opponents cannot, by any argument founded on *reason* or *necessity*, prove that what we call design, *is anything else* than design; that is to say, is *not* design. Now until this be proved the force of their objection may be considered as completely neutralized; while the objection itself becomes thus reduced to the condition of a mere sophism, that leaves everything precisely in the same state as it was at the beginning.

Having thus briefly disposed of these objections to the argument of design, we finally recur with pleasure to that *common-sense* view of the subject which we have already contended for, and which we still maintain, viz., that design is independent of the designer; in other words, that design is design, whether exemplified in the works of man or in those of his Maker—a view which has been adopted by the wise and good in all ages—which has all the probabilities on its side, and which alone, of all others, points out to man his true and natural position among created beings. When man, indeed, compares himself with the universe, his own insignificance appears quite overwhelming; but the argument of design assures him that, insignificant as he is, while he investigates and approves of the order and harmony around him, he is exerting faculties truly god-like—that his reason though limited in degree, must be immortal in kind, and thus differ from that of the great Architect of all, only in not being infinite. And hence the proud relationship in which man justly considers himself to stand with respect to his Maker! hence the grand source of that longing after a future state, where his knowledge will be consummated, and where he will no longer "see through a glass darkly"—notions at once the result and reward of his reason, and which raise him far above all other animals.

BOOK II.

OF METEOROLOGY : COMPREHENDING A GENERAL SKETCH OF THE CONSTITUTION OF THE GLOBE ; AND OF THE DISTRIBUTION AND MUTUAL INFLUENCE OF THE AGENTS AND ELEMENTS OF CHEMISTRY IN THE ECONOMY OF NATURE.

In the foregoing chapters, we have endeavoured to convey some idea of the "limits which the Deity has been pleased to prescribe to his own power;" or in other words, of the properties of the different subordinate agents and elements of our globe, and of their mode of operation. We come now to consider a little more closely the general distribution of these agents and elements ; and the principles upon which this distribution is regulated, so as to produce all the wonderful results which we see constantly going on around us in nature.

In the present state of the world, as we have already observed, the general tendency of its constituent principles seems to be towards a state of equilibrium or repose. But a very superficial examination of those parts of the earth's crust to which we can obtain access, is sufficient to convince us that this quietude has not *always* existed ; and consequently that the present state of things must have had a beginning. In short the phenomena of geology appear to show, that our earth in its progress, has undergone, alternately, periods of comparative quietude like that in which we now live ; and periods of derangement and convulsion, in which the preceding states of quietude and their consequences have been more or less subverted, and a new order of things has been induced. To enter further into details regarding these changes, however, would be quite foreign to the object of the present volume. It is the business of the Geologist to point out the changes which our earth has evidently undergone before it arrived at its present condition ; to trace the earth as it were from a state of chaos through all its metamorphoses, whether sudden and convulsive, or slow and gradual ; and to show that all these changes have not resulted from chance, but from the agency of an intelligent Being operating with some ulterior purpose, and according to certain laws, to which he had chosen to restrict himself—to demonstrate, in short, that to these very convulsions and changes we owe all that boundless variety of sea and of land, of mountain and plain, of hill and valley ; all that endless admixture of rocks, of strata and of soils, so essential to the existence of the present order of things ; without which the world would have been a mass of crystals, or one dreary monotonous

void, totally unfitted for the present race of organized beings; and particularly as a residence for man—apparently one great end and object of creation. Such is the business of the geologist; and where his duties terminate, those of the Meteorologist may be said to begin. To him it belongs more especially to consider the globe in its *present* condition of quietude or equilibrium, and the means by which this state of equilibrium is maintained: in particular, to point out the influences of heat and of light, and of the energies allied to them; to study the laws of the distribution and change of these important agents in the production of climate; to trace, in short, the effects of these wonderful principles upon the earth, the ocean, and the atmosphere, and all the infinite variety of phenomena dependent upon them.

In so wide and varied a field of inquiry it is not perhaps easy to devise a plan that shall be perfectly unexceptionable. For, as there is no one subject so entirely isolated, as not to be more or less influenced by the rest, we scarcely know which to commence with. After a good deal of reflection, we have adopted that arrangement which seems to offer the most natural view of these subjects: and at the same time appears best calculated to illustrate the design and wisdom of the Great Creator.

CHAPTER I.

OF THE GENERAL STRUCTURE OF THE EARTH: PARTICULARLY WITH REFERENCE TO THE DISTRIBUTION OF ITS SURFACE INTO LAND AND WATER; AND WITH RESPECT TO ITS ATMOSPHERE.

Section I.

Of the General Relations of the Sea and the Land to each other.

Our earth may be considered as made up of materials naturally existing in the solid, the liquid, and the gaseous state, the absolute proportions of which to each other we cannot even conjecture. Of the mean density of the whole, however, we can form some estimate; and philosophers have shown that this density lies between five and five and a half, that of water being one. We can also form a tolerably precise notion of the relative proportions of the surface occupied by the solid and the liquid materials; and of the pressure and height of the atmosphere surrounding the whole.

With the general geographical distribution of land and ocean,

we take it for granted that all are more or less acquainted. We shall, therefore, confine our remarks chiefly to their relative proportions; which are such, that nearly three-fourths of the earth's surface may be said to be covered with water, while barely one-fourth, of course, must be occupied by dry land. Of this dry land, as is well known, by far the greater part is confined to the northern hemisphere; while in the southern hemisphere, the Pacific ocean exhibits a nearly continuous surface of water, greater than the whole dry land of the globe put together. According to the estimate of Humboldt, the dry land in the two hemispheres is in the ratio of three to one; between the tropics in the two hemispheres as five to four; and without the tropics as thirteen to one; the preponderance being in the northern hemisphere.

The height of the dry land above the general level of the ocean is very various; but its utmost height, as compared with the diameter of the earth, is quite trifling; and it has been shown that if the whole of the dry land existing were equally distributed over the bottom of the sea, the quantity of water in the sea is amply sufficient to cover it entirely. Hence "dry land can be only considered as so much of the rough surface of our globe as may happen for the time to be above the level of the waters; beneath which it may again disappear, as it has done at different previous periods."*

The solid portions of our earth are all made up of various combinations of the elementary principles described in a former chapter. The relative situations these principles occupy in the earth's structure; the endless proportions in which they exist; and all the infinite diversity of their properties, it is the business of the geologist and of the mineralogist to inquire into and explain: the observations, therefore, which we have to make on the present part of our subject, will be chiefly confined to the waters of the ocean, and to the atmosphere.

Section II.

Of the Ocean.

The waters of the ocean are not pure, but contain, as is well-known, a variety of saline matters in solution. Indeed, when we reflect upon the immense relative extent and general circumstances of the ocean, we may naturally suppose that its waters will contain more or less of every existing soluble principle. By far the most abundant principle, however, in sea-water is common salt;

* De la Beche's Geological Manual p. 2.

which may be said to constitute, in general, nearly two-thirds of the whole saline matter present. The saline matter fluctuates between three or four per cent; and the specific gravity of the water varies, according to the proportion of the saline ingredients, from about 1026 to 1030; pure water being supposed to be 1000. The late Dr. Marcet, some years ago, made some interesting experiments on this subject, and the following are the general conclusions which he drew from them :—

1. That the southern ocean contains more salt than the northern ocean, in the ratio of 1.02919 to 1.02757.

2. That the mean specific gravity of sea-water, near the equator, is 1.02777; or intermediate between that of the northern and that of the southern hemispheres.

3. That there is no notable difference in sea-water under different meridians.

4. That there is no satisfactory evidence that the sea at great depths is more salt than at the surface.

5. That the sea, in general, contains more salt where it is deepest and most remote from land; and that its saltness is always diminished in the vicinity of large masses of ice.

6. That small inland seas, though communicating with the ocean, are much less salt than the ocean.

7. That the Mediterranean contains rather larger proportions of salt than the ocean.*

The saltness of the sea, therefore, is considerably influenced, at least at its surface, by the neighbourhood of large rivers, and by permanent accumulations of ice; and in this way the inferior saltness of small inland seas, particularly in high latitudes, may in general be explained, as most of these inland seas are supplied with comparatively large quantities of fresh water from the rivers flowing into them. On the other hand, the superior saltness of the Mediterranean has been ascribed to the immense evaporation from its surface; the consequence principally of its being situated in a warmer climate.

The saline contents of the ocean are of immense importance in the economy of nature. Such indeed is their importance, that it is doubtful whether the present order of things could be maintained without them. The effects of these saline matters will be more particularly pointed out hereafter. In this place we shall only remark, that by lowering the freezing point of water; and by diminishing its tendency to give off vapour, they perform the most beneficial offices. Another valuable purpose which they serve may be alluded to here, viz. the greater power of buoyancy which they communicate to water; by means of which the wa-

* Philos. Trans. 1819.

ters of the ocean are better fitted for the purposes of navigation. Nor are these the only uses of the saline matters; for there is reason to believe that they contribute in no small degree to the stability of the water; and that an ocean of fresh water would speedily undergo changes that would probably render it incompatible with animal life; such an ocean perhaps would even suffer decomposition, that might seriously interfere with the other arrangements of nature.

Lastly, who will venture to assert that the distribution of sea and of land, as they now exist, though apparently so disproportionate, is not actually necessary as the world is at present constituted? What would be the result, for instance, if the Pacific or the Atlantic oceans were to be converted into continents? Would not the climates of the existing continents, as formerly observed, be completely changed by such an addition to the land, and the whole of their fertile regions be reduced to arid deserts? Now, this distribution of sea and of land, so wonderfully adapted as it appears to be to the present state of things, depends of course in a great measure upon the *absolute quantity* of water in the world. While on the other hand, the *relative gravity* of water as compared with that of the earth, keeps the ocean within its destined limits, notwithstanding its incessant motion. Thus Laplace has shown that the world would have been constantly liable to have been deluged from the slightest causes, had the mean density of the ocean *exceeded* that of the earth! Hence the adjustment of the quantity of water and of its density, as compared with that of the earth, afford some of the most marked and beautiful instances of design.

Section III.

Of the Atmosphere.

That immense body of gaseous matters surrounding our earth, and usually known under the name of the Atmosphere, is essentially composed, as we formerly stated, of two principles, oxygen and azote, in the proportion nearly of one part of oxygen and four parts of azote. Besides these two gases, the atmosphere also contains a small and perhaps a variable quantity of carbonic acid gas, amounting upon an average to about one part in a thousand of the whole; and of water in a state of vapour, likewise a variable quantity, (as will be shown hereafter,) but usually fluctuating between one, and one and a half per cent. In addition to these, there are, probably also other matters constantly present in the atmosphere; for as the sea contains a little

of everything that is soluble in water, so the atmosphere may be conceived to contain a little of everything that is capable of assuming the gaseous form.

The atmosphere exerts a pressure or weight upon all parts of the earth's surface, on an average equal to about fifteen pounds upon a square inch; or in other words, equal in weight to a column of mercury one inch square and thirty inches high. The well-known instrument the common *Barometer* or *Weather-glass*, consists of nothing more than such a column of mercury, poised or pressed upwards into a vacuum, by the weight of the atmosphere. With the changes constantly taking place in the height of such a column, every body is familiar, and we shall have occasion to recur to them hereafter; at present it is only requisite to observe, that these changes are much less remarkable in tropical than in temperate climates. Thus, between the tropics the barometer usually varies only about one-third of an inch; while in temperate climates, the changes amount to upwards of one-tenth of the whole height.

The pressure of the atmosphere decreases as we ascend above the earth's surface; and for equal ascents, this decrease of density is in what is called geometrical progression. Thus, at three miles in height, the density of the atmosphere is only one-half of what it is at the surface of the earth, or equal to a column of mercury fifteen inches in height; at six miles, the barometer would stand at one-fourth of its usual height, or seven and a half inches; at nine miles of elevation, at three inches and three quarters; and, at fifteen miles, nearly at one inch only. Hence by far the greater portion of the atmosphere is always within fifteen or twenty miles of the earth's surface; though from various circumstances it has been inferred to extend from forty to forty-five miles in height. This height, however, must be different in different latitudes; for the rotation of the earth upon its axis, and the greater and more direct influence of the solar heat upon the earth's equatorial regions, will necessarily cause the atmosphere to be higher there than in the polar regions; at the poles, the atmosphere must be lower than over any other part of the earth's surface. These are most important circumstances in the economy of nature, as we shall see hereafter.

Much difference of opinion has existed among philosophers as to the mode in which the various principles entering into the composition of atmospheric air are associated; some maintaining that these principles exist simply in a state of mixture: others considering them as chemically united. We formerly stated that all gaseous bodies, when they combine with one another, combine with reference to their volumes; that is to say, that one volume of one gas always combines with one, two, or more similar vol-

umes of the same, or of another gas, and not with any intermediate fractional part. Now, as atmospheric air is composed essentially of one volume of oxygen and four volumes of azote, it is evident, whether its elements be in actual union or not, *that it is at least constituted upon strictly chemical principles;* whence it follows, that the composition of the atmosphere has not been the result of accident. In this point of view, therefore, atmospheric air may be considered to be as much a chemical compound as water, or any other similar body; and instead of viewing the atmosphere, according to a prevalent notion, as a mere accidental and heterogeneous appendage connected with the denser matters by no apparent tie, we may fairly rank the atmosphere among the constituent principles of our globe, and as forming a symmetrical part of the great harmonious whole.

But although atmospheric air has been thus originally constituted upon chemical principles, and probably owes to this circumstance, in no small degree, its stability; yet the mode in which its constituent elements are associated, is very different from that in which the elements of compounds in general are associated. Indeed the constituent elements of atmospheric air do not appear to be combined at all; but to be only mixed, or simply diffused through each other, in the same manner that the minute portions of carbonic acid gas and of vapour are known to be diffused through the whole atmosphere; that is to say, according to the laws of the general diffusion of gaseous bodies which we endeavoured to explain in a former chapter. To this explanation we must refer the reader for details. We shall merely observe here, that the fundamental principle of this explanation consists in the assumption, that the molecules of all bodies in the gaseous state are self-repulsive (or repulsive of one another, in preference to others), for the same reason that in the solid state they are self-attractive (or attract one another, in preference to others). When different gaseous bodies therefore, are mixed together, they will not assume a position according to their specific gravities, as they might otherwise be expected to do; but the molecules of each gas will be equally diffused throughout the whole space occupied by the mixture. Hence, one direct and most important effect of the mixed constitution of the atmosphere, is *its nearly uniform composition*, at least within the limits attainable by man—a fact that has been confirmed by innumerable analyses of the air, made in all parts of the world, both at its surface and at the greatest heights hitherto reached. Moreover, this constitution of the atmosphere not only originally produced such uniformity of composition, but it *is the cause constantly operating to preserve that uniformity* —the grand conservative principle, as it were, preventing any unequal distribution of the constituent elements of the atmosphere, which would speedily prove fatal to organic life! Were the ga-

seous principles composing the atmosphere in ever so slight a state of union, they could not readily diffuse themselves through each other; and partial accumulations of one or other of them would be constantly taking place; but as the atmosphere is at present constituted, if a little more oxygen be consumed in one spot than in another, instantly the deficiency is supplied from the neighbourhood by diffusion, and the equilibrium is scarcely affected in a sensible degree. Another curious result of this independent condition of the gaseous principles of the atmosphere is, that of the whole pressure exerted, each principle exerts its own force according to its quantity. Thus, of the thirty inches of mercury supported by the whole atmospheric pressure, the azote sustains 23 $\frac{36}{100}$ inches, and the oxygen 6 $\frac{18}{100}$ inches; while the aqueous vapour sustains only $\frac{44}{100}$ inch, and the carbonic acid still less, or only $\frac{2}{100}$ inch. Hence it is evident that the fluctuations in the height of the barometer, amounting to nearly three inches in our latitude, cannot depend altogether upon the quantity of aqueous vapour in the atmosphere; for if the whole of this vapour were annihilated, it would scarcely produce a difference in height of half an inch. Attention is now drawn to this fact for purposes that will appear in a subsequent chapter.

Lastly, had the absolute quantity, or the relative gravity, of the atmosphere been materially different from what they are, the present order of things could not have existed. Hence, the same striking evidences of wise adjustments are displayed in these arrangements of the atmosphere, as in those formerly shown to exist with respect to the quantity and gravity of the ocean.

Before we close the present chapter, let us reflect for a moment upon the great arrangements we have been considering.

Why has the surface of this earth been divided into land and sea? Why have the land and sea been so adjusted to each other, that their condition and properties hardly admit of change without destruction to the whole fabric? Why has their present stability been so wonderfully secured! Again, with respect to the atmosphere; why has there been any atmosphere thrown around this globe? and why such manifest provisions to secure its ubiquity and unvarying constitution?

Viewed alone and without reference to organized beings, all these things appear without an object. This globe might have revolved about the central luminary—might have occupied its point in the universe without any "gathering together of the waters," without any circumambient air. But the scheme of the great Creator extended beyond the mere adaptation of inanimate matter. "Before its foundations were laid," He had destined this earth to teem with life, and throughout has displayed his original design of rendering it a fit habitation for living beings.

For this purpose and acting at the same time, in strict conformity to those laws, by which He had chosen to limit himself, He has, by means of successive convulsions and changes, so contrived to mix and blend the different elements, and finally so to arrange the dry land apart from the sea; that, taken as a whole, and with reference to the present order of things, their relative proportions will scarcely admit of material change. While, to crown his works, and as it were, the more strongly to evince his design, and his wisdom, He has surrounded the whole with an atmosphere, to preserve the homogeneity of which, its principles have been so associated, as to constitute an exception to his usual operations, and even to the general laws of nature!

CHAPTER II.

OF HEAT AND LIGHT—THE MODES OF ESTIMATING THEIR DEGREE, AND THE WAYS IN WHICH THEY ARE PROPAGATED. OF THE GENERAL TEMPERATURE OF THE CELESTIAL REGIONS, AND OF THE EARTH INDEPENDENTLY OF THE SUN.

Section I.

Of Heat and Light, and the Modes of estimating their Degree.

Our sensations are a very imperfect and uncertain measure of temperature, and when we wish to speak with precision on that subject, it becomes necessary to have recourse to other means of comparison. For the sake of the general reader, we shall, therefore, in the first place, briefly describe the principles of the construction of the *Thermometer*, the instrument for measuring heat.

All bodies, as we have shown in a former chapter, become more or less expanded when they undergo an increase of temperature. Hence the relative degrees of expansion of a body may be employed as a sort of measure of the degree of heat; and most of the thermometers employed, act upon this principle. Thus the common thermometer, as is well known, consists of a portion of some fluid, generally of mercury, enclosed in a small glass ball furnished with a hollow stem, the narrow bore of which communicates with the general cavity of the ball. We shall suppose the quantity of the mercury, and the size of the ball, to be so adjusted to each other, that when the instrument is placed in ice on the one hand, and in boiling water on the other, the whole expansion of the mercury between these two fixed points, shall fall within the range of the stem or tube. The points at which the

mercury stands in the tube, at the freezing and boiling temperatures are to be accurately noted; and the intermediate space upon the scale attached to the tube, is to be divided into 180 equal parts or degrees; the freezing point is to be marked 32°, and of course, the boiling point 180° above, or 212°. Such is *Fahrenheit's* scale, the one employed in this country, and to which the numbers hereafter mentioned refer. In other countries different scales are made use of; and in France particularly, what is termed the *centigrade* thermometer is generally adopted. In this thermometer the freezing point is marked 0° and the boiling point 100. In other parts of the continent *Reaumur's* scale is much used. In Reaumur's the freezing point, as in the Centigrade, is 0°, but the boiling point is only 80°. These different graduations are easily convertible, but it is much to be regretted that they exist, as they cause considerable trouble and confusion.

The instrument employed for measuring the intensity of light is termed a *Photometer;* of such an instrument various forms have been proposed, but at present they are all very imperfect.

Section II.

Of the Propagation of Heat and Light.

The modes in which heat and light are propagated from one body to another, and through the same body, have been already explained, and we need not again enter into details: a brief recital here, however, of the modes in which heat and light are propagated, may not be unacceptable to the general reader.

Heat passes from the sun to the earth by *radiation;* and again, by the same process, it is freely sent off from the surface of the earth into the atmosphere. Below the surface of the earth, heat is propagated in all directions through the *solid* matter, by what is called *conduction.* A third mode in which this important agent is extensively propagated in nature, is by the means we have termed *convection,* or the *carrying* process. Convection is confined, of course, to fluids, as water and air. A portion of water or of air being heated above, or cooled below the surrounding portions, expands or contracts in magnitude, and thus becoming specifically lighter or heavier, rises or sinks accordingly; carrying with it, the newly acquired temperature, whatever that temperature may be.

Light, at present, is only known to be propagated by radiation.

By bearing in mind these modes of the propagation of heat and light, the general reader will find no difficulty in understanding what follows.

Section III.

Of the Temperature of the Celestial Regions.

From the close and intimate relations between heat and light, and from their almost invariable association as they exist around us, it seems not very unreasonable to conclude that these agencies are generally associated in nature; and that wherever one is present, there the other must be present also. If this be really the case, the innumerable fixed stars, considered to be so many suns, must be supposed capable of diffusing heat as well as light throughout the celestial regions; and consequently there must be a certain degree of temperature common to the whole. For this reason, and for others that might be mentioned, philosophers have not only inferred the existence of such a common temperature existing throughout the celestial regions, independently of our sun; but have even attempted to determine its degree. Moreover, it is singular that all the different modes which have been employed to estimate this temperature, concur in showing that it does not differ much from —58° of Fahrenheit's scale; that is to say, about 90° below the freezing point of water; a degree of cold "not greatly inferior to that at which quicksilver becomes solid, and much superior to some degrees of cold which have been produced artificially."* If such a common temperature really exists throughout space, or at least in our planetary system, it must have no inconsiderable influence upon the temperature of the planets generally; and with respect to our own globe in particular, such a common temperature must operate by diminishing the intensity of the cold around the poles.

Section IV.

Of the Temperature of the Interior of the Earth.

The attention of philosophers has, for some years past, been a good deal directed to the internal temperature of the earth, at great depths, beyond the influence of the sun or of any other external cause. From the earliest times some vague notions of a central heat seem to have existed among mankind; doubtless, arising from their attention being forcibly drawn to the phenomena of

* Discourse on the Study of Natural Philosophy; p. 157. By Sir J. F. W. Herschell.

volcanoes and hot springs; but it is not till a comparatively late period that the subject has been carefully investigated. It would be quite foreign to our design to enter here into details upon this point; we shall therefore merely state, that the arguments in favour of the probability of a central heat are—"first, the experiments made in mines, which, notwithstanding their liability to error from various sources, still seem to show, particularly those made in the rock itself, an increase of temperature from the surface downwards;—secondly, the existence of thermal springs, which are not only abundant among active and extinct volcanoes, but also among all varieties of rocks in various parts of the world;—thirdly, the existence of volcanoes themselves, which are distributed over the globe, and present such a general resemblance to each other that they may be considered as produced by a common cause, and that cause, probably, deep-seated;—and lastly, the terrestrial temperature at comparatively small depths, which does not coincide with the mean temperature of the air above it."*

Such is an abstract of the principal arguments which have been brought forward in support of the opinion, that within our earth, even at the present time, there exists a central heat of great intensity. As corroborative of the same views, may be mentioned the evidence derived from the characters of the fossil remains both of plants and of animals, found in the colder regions of the world; which characters are such as to prove beyond a doubt, that these plants and animals must have existed in a climate much hotter than that in which their remains are found, and indeed, of equal, if not of superior, heat to that of the tropical portions of our earth at this time. Hence it has been inferred, that the temperature of our earth, formerly much above what it is now, has been gradually dissipated into the surrounding planetary regions, and thus helped to increase the general temperature, above stated, as supposed to exist throughout space. Moreover, the same distinguished philosopher,† to whom we are principally indebted for these observations, has attempted to show that the earth has nearly reached its limit of cooling, particularly near the surface. Near the surface the temperature would necessarily decrease much more rapidly than in the interior; where, in a globe of the earth's magnitude, the temperature might be supposed to remain nearly unchanged for a very great length of time. He has also attempted to show that the temperature of the surface is still liable to be influenced, by the gradual escape of heat from the interior which even yet seems to be constantly going on; and that the temperature of the surface is thus somewhat higher than it would be if such a central

* De la Beche's Geological Manual, p. 24, new ed.
† Baron Fourier.

heat did not exist; or than if the temperature of the surface of the earth depended only upon the action of the sun. And this brings us to the point at which our subject may be said properly to begin, viz. the consideration of the *present state* of the earth's temperature, as liable to be influenced by the presence or absence of the sun, the great source of heat and of life to our system.

Before proceeding, we may remark, that the details of the subject we have now concluded, fall entirely within the province of the geologist. To him it belongs, as we have already said, not only to trace the wonderful changes which our globe has undergone in arriving at its present condition, but to point out the beautiful adaptations of organic life and structure to the existing circumstances of its various epochs. Considered in this point of view, geology is a subject of the highest interest and importance; and, to use the words of an eminent Professor, with which we shall finish this chapter, "lends a great and unexpected aid to the doctrine of final causes; for it has not merely added to the cumulative argument, by the supply of new and striking instances of mechanical structure adjusted to a purpose, and that purpose accomplished; but it has also proved that the same pervading active principle manifesting its power in our times, has also manifested its power in times long anterior to the records of our existence.

"But, after all," continues our author, "some men, seeing nothing but uniformity and continuity in the works of nature, have still contended (with, what I think, a mistaken zeal for the honour of sacred truth) that the argument from final causes proves nothing more than a quiescent intelligence. I feel not the force of this objection. In geology, however, we can meet it by another direct argument; for we not only find in our formations organs mechanically constructed, but at different epochs in the history of the earth we have great changes of external conditions, and corresponding changes of organic structure; and all this without the shadow of a proof that one system of things graduates into, or is the necessary and efficient cause, of the other. Yet in all these instances of change, the organs, as far as we can comprehend their use, are exactly those which were best suited to the functions of the being. Hence, we not only show intelligence contriving means adapted to an end, but at successive times and periods contriving a change of mechanism adapted to a change in external conditions. If this be not the operation of a prospective and active intelligence, where are we to look for it?"*

* Address delivered to the Geological Society of London, by the late President, Professor Sedgwick, 1831.

CHAPTER III.

OF THE TEMPERATURE OF THE EARTH AT ITS SURFACE, AS DEPENDENT ON THE SUN.

The general temperature of the earth is doubtless regulated by its situation in the universe, and more especially by its position with respect to the sun. To this position, as formerly observed, the properties of its constituent principles have, most obviously, been all adapted with consummate wisdom; so that, under the circumstances in which they are placed, some are solid, some liquid, others gaseous, according to the purposes they are intended to fulfil in nature.

But the heat and light derived from the sun are very unequally distributed over the surface of the earth; and every one is familiar with the fact, that as we recede from the equator towards the north or south, the temperature of the earth's surface gradually diminishes till we arrive at the polar regions.

Such is the general fact. But the circumstances which conspire to interfere with this gradual distribution of temperature are so numerous and so influential, that the actual temperature of a place can be learnt only by observation. Among the circumstances thus more especially affecting the distribution of temperature, may be mentioned the nature of the surface, whether water or land,—and the situation, whether at a greater or at a less height above the level of the ocean. To these may be added the particular configuration and geographical relations of places: such as their aspect to the north or south; their being sheltered or exposed; the composition and nature of the soil, such as its colour and state of aggregation, on which depend its powers of absorbing and of radiating heat and light, and of retaining or of parting with humidity, &c.; also the proximity or absence of seas; the predominancy of certain winds; the frequency of clouds, fogs, &c. These, and innumerable other circumstances, many of which will be pointed out in subsequent chapters, contribute to influence the temperatures of particular places, and to render them, in fact, as varied as the places themselves.

Nor is difference of place the only cause of vicissitude of temperature; every one knows that at the *same* place the temperature is in a constant state of change. Hence before we can obtain correct notions of the actual temperature of any given place or period, certain expedients are necessary which we have in the first place to consider.

Section I.

Of Mean Temperature.

If, on any given day, we observe the temperature at the earth's surface, at the commencement of every one of the twenty-four hours, we shall find, as before observed, that at each hour the temperature is different; and we naturally inquire which of all these temperatures is to be chosen in preference, as the one characteristic of the day and place? The answer to this question obviously is; *that temperature, whatever it may be, which is equidistant from the extremes*, or, as it is usually termed, the *mean temperature of the whole*. Now this mean temperature may be obtained, nearly, by adding all the results together, and dividing the sum by the number of observations; thus we arrive at the mean temperature of the day, by adding together the temperatures observed at different hours of the day, and dividing the sum by the number of temperatures. In the like manner by adding together the mean temperatures of every day of a week, or of a month, and dividing the sum by the number of days, we obtain the mean temperature of the week or month; and so on, by similarly treating the mean temperatures of the months, or of any number of years, we obtain the *mean* temperature of the year, at a given place: and it is to be observed that the greater the number of observations the more accurate will be the mean result.

Lastly, it remains to state that the temperature always understood by the Meteorologist (except otherwise expressed) is that of the air near the surface of the earth, as indicated by a thermometer effectually protected from radiation and foreign influence of every kind. The temperature as indicated by a thermometer fully exposed to solar radiation, and which in its turn is allowed to radiate freely in the sun's absence, is altogether a different thing; and may be imagined to coincide very nearly with the actual temperature of the earth's surface, when similarly exposed. The fluctuations of temperature indicated under these circumstances are much greater than those of the air above noticed, though it is probable that the mean of the whole of such observations, if this mean could be accurately obtained, would differ little from the mean of those of the air.

Section II.

Of the actual Distribution of Temperature over the Globe. Of Isothermal Lines, &c. Climate.

The reader is supposed to be acquainted with the principles of the common division of the surface of the globe into five zones or portions, usually denominated the *torrid*, the two *frigid*, and the two intermediate *temperate zones;* and that generally speaking the poles and the equator present the extremes of temperature upon the earth's surface. Now, in considering the general distribution of temperature over the globe, the extreme temperatures naturally claim our attention in an especial manner: we shall, therefore, in the first place, proceed to consider the temperature of the polar and of the equatorial regions.

Of the Temperature of the Poles and of the polar Regions.— The probable mean temperature of the poles has always been an interesting subject of meteorological inquiry. It must be confessed, however, that after all that of late years has been done by our enterprising countrymen, much is yet necessary to enable us to arrive at satisfactory conclusions. Thus it has been shown that in attempting to calculate the temperature of the North Pole, we shall obtain very different results by employing the temperature occuring in the old world, and that observed in the new world; the temperature of the old world indicating the temperature of the pole to be about 10°; while the temperature of the new world indicates it to be considerably below Zero. Hence it has been inferred, that there are two points or poles of greatest cold situated in about the latitude of 80° north, and in longitudes 95° east, and 100° west; and consequently that the geographical pole of the globe is not the coldest point of the Arctic hemisphere. Whether this deduction be well founded or not must be decided by future observation. At present the actual temperature of the Polar regions cannot be considered as determined.

Although we are thus unable to state with certainty the temperature of the Polar regions, it may nevertheless be deemed an object of curiosity to know the *lowest* temperatures that have been noticed. Perhaps the lowest *authentic* observations of temperature we possess are those by Captain Parry at Melville Island. Here the thermometer in the ship was often observed as low as —50°; and at a distance from the ship even as low as 55° under Zero. We believe still lower temperatures than these are on record, but probably they are not to be relied on. The greatest degree of cold hitherto produced *artificially* has been 91° under Zero.

Of the mean annual Temperature of the Equator. The mean annual temperature of the equatorial, like that of the polar regions, is a meteorological problem of considerable interest. Humboldt, from a very extensive generalization, fixed the mean equatorial temperature at 81½°; and the same temperature has been adopted by others. Attempts, however, have been recently made to show that this temperature is 3° or 4° below the truth; but Humboldt in reply still maintains his former opinion. Since at the equator, only about one-sixth of the whole circumference of the globe is dry land, the general equatorial temperature, as actually found to exist, is perhaps lower than upon theoretical principles it ought to be; and certainly much below what it ought to be, as deduced from observations made on the continent in the neighbourhood of the equator. Thus the mean temperature of Pondicherry, in latitude 11° 55′ north is at least 85°; and if from this temperature that of the equator were deduced according to the common principles, the deduction would of course be much above the truth. The fact is, as in the case of the Polar regions, we do not possess the requisite data for determining the equatorial temperature in a perfectly satisfactory manner.

As in speaking of the Polar regions, we noticed the *lowest* degree of temperature which had been observed, perhaps while speaking of the equatorial regions it may not be deemed irrelevant to notice the *highest* temperature. Observations, however, of this kind, being principally founded on the incidental notices of travellers, are not, in general, much to be relied on; or are to be considered only as approximations. Thus the thermometer has been recorded at Benares to stand at 110°, 113°, and even 118°. At Sierra Leone, it has been observed, when placed on the ground to indicate a temperature of 138°. Humboldt also gives many instances of the temperature of the surface of the earth, amounting to 118°, 120°, and 129°; and on one occasion he found the temperature of a loose and coarse granitic sand to amount to upwards of 140°, the thermometer in the sun at the time only indicating a temperature of about 97°.

Of the Temperature of the intermediate Regions of the Globe. Of Isothermal Lines, &c. With respect to the temperatures of those parts of the earth between the poles and the equator, it may be remarked, that, except for reference only, the old division, before mentioned, of the earth's surface into zones is now almost entirely superseded by the more precise and natural arrangement, termed the *Isothermal* arrangement. According to this arrangement, all the places upon the globe having *the same annual mean temperature* are classed together; and lines drawn upon a map through such a series of places, have been termed *Isothermal*

lines, or *lines of equal temperature*. As might be expected from what has been already stated, the courses of these lines are by no means regular. Thus, suppose two travellers set out, the one from London and the other from Paris, and each visit all the places in the northern hemisphere in which the mean annual temperatures are the same as in these two cities. It will be found that the lines of their routes, or the isothermal lines of these two cities, will not only not follow the parallels of their latitude, but that they will not be parallel to each other; and the same may be said to be the case with any other two places upon the globe. Hence, as the isothermal lines are as numerous as the places, and as diversified as numerous, geographers have grouped them into bands or zones. Thus Humboldt (to whom we owe most that has been done on this subject) has divided the northern hemisphere into the following six isothermal bands or zones, viz.:

1. The zone of mean annual temperature ranging from 32° to 41°.
2. - - - - from 41° to 50°.
3. - - - - from 50° to 59°.
4. - - - - from 59° to 68°.
5. - - - - from 68° to 77°.
6. - - - - from 77° upwards.

The tables given in the appendix contain a general view of Humboldt's results. We shall content ourselves with briefly pointing out the approximate course of the most interesting of these lines, viz. *the Isothermal line of* 32°.

If we begin to trace this important line from the eastern parts of Siberia in longitude 130° east, we shall find that in this meridian it commences nearly in the latitude of 59° north; whence it makes a gradual bend northwards, and crosses the parallel of 60°, nearly in longitude 90°. From this point it still advances to the northward, and crossing the arctic circle in longitude 45° east, arrives at its most northern extremity in about latitude 67½°, longitude 10° east. From this its most northerly limit our line takes a gradual sweep towards the south, recrosses the arctic circle in longitude 15° west, and passing through the north-west of Iceland, divides the parallel of 60° in longitude 42° west. From this spot it proceeds southwards to the latitude of 54°, a little to the north of Table Bay, in Labrador; gradually declining in its course till it arrives at longitude 100° west, in the central parts of the new continent. Hence the Isothermal line of 32°, ranges through a space of 14° or 15° of latitude; while its western extremity, in the central parts of America, is 5° or 6° nearer the equator than its eastern extremity in Siberia—a circumstance strikingly illustrative of the greater cold of the new

continent in the same parallel of latitude. The most remarkable circumstance connected with them is, that as they approach the equator they gradually become less convex towards the north, so that the Isothermal line of 77° differs but little from a straight line, coincident with the tropic of cancer.

In the arrangement above described the mean temperatures of *the whole year* are supposed to be classed together; but it is obvious that the same principle may be applied to any portion of the year, as the extreme winter and summer temperatures. Such classifications are often, as we shall presently see, of great importance in enabling us to estimate the characters of a particular country. Thus, lines drawn through places having the same summer and the same winter temperatures, are denominated *Isotheral* and *Isocheimal* lines; while lines drawn through places having other common temperatures, receive other appropriate names.

After these general remarks, we proceed to give a summary sketch of the actual distribution of temperature over the *northern hemisphere*, which we shall subjoin in the words of Humboldt.

"The whole of Europe," says this distinguished philosopher, "compared with the eastern parts of America and Asia has an insular climate; and upon the same Isothermal line the summers become warmer, and the winters colder, as we advance from the meridian of Mont Blanc towards the east or the west. Europe may be considered as the western prolongation of the old continent; and the western parts of all continents are not only warmer at equal latitudes than the eastern parts; but even in the zones of equal annual temperature, the winters are more rigorous, and the summers hotter on the eastern coasts than on the western coasts of the two continents. The northern part of China, like the Atlantic region of the United States, exhibits seasons strongly contrasted; while the coasts of New California and the embouchure of the Columbia have winters and summers almost equally temperate. The meteorological constitution of those countries in the north-west resembles that of Europe as far as 50° or 52° of latitude. In comparing the two systems of climates, the concave and the convex summits of the same Isothermal lines, we find at New York the summer of Rome and the winter of Copenhagen; at Quebec, the summer of Paris and the winter of St. Petersburgh. At Pekin, also, where the mean temperature of the year is that of the coasts of Brittany, the scorching heats of summer are greater than at Cairo, and the winters are as rigorous as at Upsal. So also the same summer temperature prevails at Moscow, in the centre of Russia, as towards the mouths of the Loire, notwithstanding a difference of 11° of latitude; a fact that strikingly illus-

trates the effects of the earth's radiation on a vast continent deprived of mountains. This analogy between the eastern coasts of Asia and America sufficiently proves," continues Humboldt, "that the inequalities of the seasons depend on the prolongation and enlargement of continents towards the pole; on the size of seas in relation to their coasts; and on the frequency of the north-west winds, and not on the proximity of some plateau or elevation of the adjacent lands. The great table lands of Asia do not stretch beyond 52° of latitude; and in the interior of the new continent, all the immense basin bounded by the Alleghany range, and the rocky mountains, is not more than from 656 to 920 feet above the level of the ocean."

The following remarks apply to *the temperature of the southern hemisphere.*

The general temperatures of the northern and of the southern hemispheres are understood to differ very considerably. This difference, however, does not depend upon any material difference in the proportion of heat and light derived from the sun, as will be presently shown; but on the very unequal distribution of sea and of land in the two hemispheres. The small quantity of land in the southern hemisphere contributes not only to equalize the seasons, but also to diminish the annual temperature of that part of the globe; and hence the Polar ice in the southern hemisphere advances more towards the equator than in the northern hemisphere, particularly where the Antarctic Ocean is free from land.

Humboldt has shown, that near the equator, and indeed so far south as 40° or 50°, the correspondent Isothermal lines are in both hemispheres almost equally distant from the poles; and that, in considering only the transatlantic climates between 70° and 80° of west longitude, the mean temperatures of the year, under corresponding geographic parallels, are even greater in the southern than in the northern hemisphere. It is the *division* of heat, therefore, between the different seasons of the year, rather than the absolute amount of heat during the whole year, that gives a particular character to southern climates, and approximates them generally to the character of insular climates. Thus, in the southern hemisphere, and on the Isothermal lines 46.4° and 50° we find summers which, in our hemisphere, belong only to the Isothermal lines of 35.6° and 40°. The mean temperature is not precisely known beyond 51° of south latitude; yet there is no reason to infer that the Isothermal line of 32° is much further from the south pole, than in the opposite hemisphere, the similar line is from the north pole; and some circumstances at first sight appear to show that the Isothermal line of 32° is even nearer to the south pole than it is to the north pole; though these circumstances are probably deceptive. With respect to the temperature

of the south pole itself, like that of the north pole, we have no means of forming an accurate estimate.

Such is a summary account of the general distribution of temperature over the northern and southern hemispheres. Now amidst the infinite changes every where going on, there is nevertheless at the same place a certain average state of things which taken together, constitute what is called the CLIMATE of the place. Of climate, undoubtedly, temperature is the most important ingredient. But the circumstances, besides mere temperature, which enter into the formation of climate, are so numerous and diversified, and their operation, in consequence, is so complicated, that it becomes exceedingly difficult to unravel and display them in a satisfactory manner. The constituents of climate, however, appear to be most naturally divided into two great sections; viz., *those of a* PRIMARY *kind depending upon the globular figure of the earth; upon its motion in its orbit, and upon its axis: and those of a* SECONDARY, *or subsidiary kind, more immediately connected with the globe itself, and depending upon the nature of its surface, as composed of land or water;* or, *as connected with its atmosphere.* Under these two points of view, we purpose to consider the subject of CLIMATE, in the following chapters.

CHAPTER IV.

OF THE PRIMARY CONSTITUENTS OF CLIMATE: OR, OF THE TEMPERATURE OF THE EARTH, AS DEPENDENT ON ITS GLOLULAR FORM; AND ON ITS ANNUAL AND DIURNAL MOTIONS.

THE distance of the earth from the sun is such, that the solar rays may be supposed to arrive at the earth's surface in a state of parallelism. Now, when parallel rays fall upon a globe, it is obvious that any number of such rays falling perpendicularly, as at the equator of our earth, will occupy a very different portion of the surface of the globe, from what an equal number of the same rays will occupy where they fall obliquely, as in our polar regions. Hence, as we recede from the equator towards each pole, heat and light are diffused over gradually increasing portions of the earth's surface, and thus the intensity of both decreases in a like proportion. The exact law of such decrease is well known to mathematicians, but need not be here repeated. For our present purpose it is sufficient to observe, that among the natural causes affecting the distribution of heat and light in different latitudes, the globular figure of the earth is the principal.

The second great natural cause of the unequal distribution of

heat and light over the earth, is the obliquity of the earth's motion in its orbit with respect to the plane of its equator. From this obliquity it happens that, during the annual revolution of the earth round the sun, every part of its surface, between the latitudes of $23\frac{1}{2}°$ north and south from the equator, is in turn exposed to the perpendicular influence of the sun. To this oblique motion of the earth in its orbit we owe the endless variations and vicissitudes of seasons in different latitudes.

There is also another circumstance connected with the earth's motion in its orbit, which, as partaking of the character of a primary cause, may here be briefly noticed. The earth's orbit is not a circle, but an ellipse, of which the sun occupies one of the *foci*. Now, it has been so arranged, that in the middle of our winter, the earth is in that part of its orbit which is nearest to the sun. The earth, therefore, is at Christmas actually about three millions of miles nearer to the sun than at Midsummer. Hence it might be inferred that the temperature of the southern hemisphere, which during our winter is directly exposed to the sun, would be affected by this greater proximity. Such, however, is not the case ; for this greater proximity to the sun is almost exactly counterbalanced by the swifter motion of the earth along this part of its orbit. The eccentricity of the earth's orbit, therefore, has little or no influence on its temperature as at first sight might be supposed.*

The third great natural cause affecting the distribution of heat and light over the earth is the earth's revolution on its axis. To this revolving motion we owe the innumerable minor vicissitudes of temperature, and of light and shade, daily and hourly experienced throughout the world.

Such are the three great natural causes which regulate the distribution of heat and light over our globe. They may be considered as the necessary results of more general laws to which the Great Author of nature has chosen to restrict himself, and to which,

* Or, perhaps, to quote the more precise explanation of Sir J. Herschel, "The momentary supply of heat received by the earth from the sun varies in the exact proportion of the angular velocity, that is of the momentary increase of longitude. Hence the greater proximity of the sun in the winter is exactly compensated for by the earth's more rapid motion, and thus an equilibrium of heat is, as it were, maintained. Were it not for this, the eccentricity of the orbit would materially influence the transition of the seasons ; and the effect would be to exaggerate the difference of summer and winter in the southern hemisphere, and to moderate it in the northern ; thus producing a more violent alternation of climate in the one hemisphere, and an approach to perpetual spring in the other. As it is, however, one such inequality subsists, but an equal and impartial distribution of heat and light is accorded to both." Treatise on Astronomy, p. 198, (Lardner's Cyclopædia).

as usual, He most rigidly adheres. Why, among the numerous possible means by which heat and light might have been, and in other instances, are distributed from a central sun over a distant planet, these regulating causes have been selected for our earth, is absolutely unknown to us. That this selection has been made with some ulterior view we cannot hesitate to believe; and one such view or purpose may have been to demonstrate to us His wisdom and His power, by the methods chosen for obviating the difficulties necessarily resulting from these primary arrangements. In other planets, where other primary arrangements for the distribution of heat and light have been adopted, there are probably other modes of obviating the difficulties arising from them. Of such arrangements we can form no conception; but to the inhabitants of these planets, they are doubtless an equal evidence of the wisdom and the power of the Deity.

CHAPTER V.

OF THE SECONDARY OR SUBSIDIARY CONSTITUENTS OF CLIMATE: COMPREHENDING A SKETCH OF THOSE CIRCUMSTANCES CAPABLE OF INFLUENCING CLIMATE WHICH ARE MORE IMMEDIATELY CONNECTED WITH THE SURFACE OF THE GLOBE, AS CONSISTING OF LAND OR WATER; OR WHICH ARE CONNECTED WITH THE ATMOSPHERE.

In the preceding chapter we have alluded to the difficulties or exigencies necessarily arising from the modes in which heat and light are distributed over our globe; and of these, before we proceed, it may be proper to specify some of the most striking.

Had the heat and light derived from the sun to the earth not been in any way modified, the equatorial and the polar regions would have been alike inaccessible to organic life. The heat within the tropics and the cold towards the poles, would both have been destructive; while the intermediate regions would have been exposed to a constant succession of violent and sudden alternations of temperature, that would have rendered the present state of things no less an impossibility. In order, therefore, to render this earth an appropriate dwelling-place for such beings as at present occupy its surface, it was necessary that these extremes and sudden vicissitudes of temperature should be in some way diminished and alleviated. Accordingly these objects have been effected with the most consummate wisdom. Indeed, some of the most splendid instances of design in nature are offered by those subsidiary arrangements, by which the difficulties necessarily arising from the primary arrangements are obviated or mitigated; and by which the greater portion of the earth's surface has been made ac-

cessible to organic beings of the same general character. These subsidiary arrangements it will be our business to explain in the present chapter.

The secondary or subsidiary constituents of climate naturally divide themselves into two great sections; viz., *those connected with the surface of the globe, as composed of land or water;* and *those connected with the atmosphere.*

In the following sketch of these constituents of climate we have endeavoured as usual to elucidate principles rather than to enter into details; and, as far as is compatible with a general and popular view, have attempted to point out the modes in which the laws of light and heat, described in the first Book, operate, so as to produce the phenomena of climate.

Section I.

Of the secondary Constituents of Climate, immediately connected with the Surface of the Globe; and depending on the Nature of that Surface as composed of Land or Water.

In attempting to illustrate the operation of the laws of heat and light in the formation of climate, we shall follow the order nearly in which these laws were discussed in the previous chapters; that is to say, we shall first consider the influence of heat and light as depending on their latent and decomposed forms; and afterwards their influence as depending on their radiation, conduction, and convection.

In the prosecution of this difficult inquiry, the first circumstance which naturally claims our attention, is the absolute quantity of heat and light derived from the sun to the earth.

1. *Of the Proportion of Solar Heat and Light that actually arrives at the Surface of the Earth.* Of the absolute quantity of heat and light derived from the sun to our globe we have no means of forming an exact estimate. M. Pouillet has attempted to show that the amount of heat annually received by the earth from the sun, is equal to that which would be required to melt a stratum of ice nearly forty-six feet thick, and covering its whole surface.* This estimate, however, is to be viewed only as a rude approximation. The difficulty lies not only in the impracticability of forming precise notions of the heat and light, which actually arrive at any given place in a given time; but in the utter impossibility of forming even a conjecture of those portions, which become latent or are otherwise lost in the passage of the solar rays through the

* Elémens de Physique expérimentalé et de Météorologie, tom. ii. p. 704.

atmosphere. The following observations will give some idea of the absolute quantity of light which reaches the earth; but it is proper to apprize the reader, that the results stated are to be considered as liable to much uncertainty. Nor do we know whether they are equally applicable to heat, which, though it obeys laws somewhat analogous to those of light, may nevertheless have its own peculiar laws.

A vertical ray of light, in its passage through the clearest air, has been calculated to lose at least a fifth part of its intensity before it reaches the earth's surface. From this cause, and from the actual condition of the atmosphere, it has been estimated that under the most favourable circumstances, of a thousand rays emanating from the sun, only 378 on a medium, can penetrate to the surface of the earth at the equator, 228 at the latitude of 45°, and 110 at the poles; while in cloudy weather these several proportions are a great deal less.*

At present, our attention is solely directed to those portions of heat and light which thus make their way to the earth's surface. On those portions retained in the atmosphere we shall offer a few remarks hereafter.

2. *Of the Distribution of Heat and Light over the Earth's Surface in the latent and decomposed Forms.* The distribution of heat and light in the *latent* state over the surface of the globe, probably follows laws nearly similar to those of the distribution of sensible heat and light formerly mentioned; that is to say, the quantity latent, like the quantity sensible, diminishes from the equator toward the poles. On this subject, however, we want the necessary data, even for forming an opinion, much less for determining the amount and the exact law of distribution; all of which must be left for future inquirers. But of the infinite importance of the latency of heat, in the economy of nature, the following brief remarks will serve to convey some notion.

Let us take the familiar instance of water, than by which important fluid, the influence of the latency of heat cannot perhaps be more strikingly exemplified. We formerly showed that the temperature of water in becoming solid on the one hand, and gaseous on the other, makes, as it were, a pause; and that these changes never take place abruptly. The consequence of this arrangement is, that ice and vapour are formed slowly and gradually, and as slowly and gradually again become water; while sudden transitions from one state to the other are thus entirely prevented. Were it not for this beautiful provision, we should be constantly liable to inundations, and other inconveniences, that would absolutely have rendered the world uninhabitable. It is

* Article Climate in the Encyclopædia Britannica.

impossible, therefore, to reflect upon the arrangement itself, or upon the means by which it has been effected, without being impressed with the most profound admiration, not only of the wisdom of the Great Designer of the whole, but of his goodness and benevolence.

The distribution of heat and light in the *decomposed* forms, like the other conditions of these great principles, decreases from the equator towards the poles. We formerly alluded to the opinion that heat, whatever it may consist of besides, appears occasionally to be convertible into the electric and magnetic energies. This conversion, under certain circumstances, may be true of sensible heat; but heat, in the latent or combined form, is perhaps most liable to be so converted. Without pretending to offer any opinion, one way or the other, on this view of the nature of heat, we shall, nevertheless, adopt it for the sake of convenience, and shall, therefore, next consider the subject.

Of the General Distribution of Electricity and Magnetism over the Earth. The recent discoveries on the connection of electricity and magnetism, formerly described, have thrown much light on the distribution of these important agencies over the globe; and the present extent of our knowledge regarding them will be understood by the general reader from the following summary.

Every one is familiar with the ordinary phenomena of a magnetic needle freely suspended, and with its tendency to assume a position more or less approaching to parallelism to the earth's axis; that is to say, that all over the world it points nearly north and south. Most persons, probably, are also acquainted with the phenomenon termed the *dip* or *inclination* of the magnetic needle: thus, in the latitude of London, a needle exactly poised and freely suspended, instead of assuming a horizontal position, will settle at an angle of 70°, the north pole being downwards. If we carry such a needle southwards, towards the equator, we observe that the dip gradually diminishes; till at a certain point, nearly coinciding with the earth's equator, it has no dip at all, but assumes a perfectly horizontal position. As we still proceed towards the south, the dip again makes its appearance, but in an opposite direction, the south pole being now next the earth's surface. To understand the reason of this *dip* of the magnetic needle and of its general direction, we have only to consider that the earth itself is a magnet, the poles of which are situated beneath its surface. The directive property of the needle is owing to these poles; and when the needle is on the north side of the equator, the north pole of the earth having the greatest effect, the needle is attracted downwards, towards the north pole; hence, exactly over the pole the needle would be vertical. Similar phenomena happen in the southern hemisphere; but here the south pole predominates, and,

of course, depresses the corresponding pole of the needle; while, at the magnetic equator, from the equal action of both poles, the needle will assume an exactly horizontal position. It may be remarked, that neither the magnetic poles nor the magnetic equator coincide exactly with those of the earth; and that this non-coincidence is owing to, or rather constitutes, what is termed the *variation* of the needle; which is not only different in different parts of the world, but appears to be liable to periodical differences in the same place, at present not well understood. Such are the principal phenomena of the magnetic needle as demonstrative of the earth's magnetism, and which we shall now attempt to illustrate a little further.

We have mentioned, that the earth may be considered as a great magnet. Now, we have formerly shown that when a magnetic needle is in its natural position of north and south, there exist electrical currents in planes at right angles to the needle, descending on its east side, passing under it from east to west, and ascending on its west side. Hence, we must suppose currents of electricity to circulate within the earth, more especially near its surface, and to be constantly passing from east to west, in planes parallel to the magnetic equator; which electrical currents, if such can be demonstrated to exist, will in their turn completely account for the magnetic directive property of the earth. The next question is, therefore, how far we are justified in assuming the existence of such electric currents within the earth?

We have already alluded to the opinion that heat occasionally passes into the electric and magnetic energies; an opinion which some consider to derive much probability from the phenomena of what has been termed *thermo-electricity;* that is to say, electricity (and magnetism) developed by the unequal distribution of heat through bodies. Now, whether the phenomena of thermo-electricity actually depend on the decomposition of heat, latent or sensible, or upon any other cause, is of little importance; the phenomena themselves are well established, and they seem to account, in the most satisfactory manner, for the general distribution of electricity and magnetism over the earth. The explanation is this: the earth during its diurnal motion on its axis from west to east, has its surface successively exposed to the solar rays in an opposite direction, or from east to west. The surface of the earth, therefore, particularly between the tropics, will be heated and cooled in succession, from east to west, and currents of electricity, on thermo-electric principles, will at the same time be established in the same direction: now these currents once established from east to west, will, of course, give occasion to the magnetism of the earth from north to south. Hence the magnetic directive power of the earth, in a direction nearly parallel with its axis, is derived from the thermo-electric currents, induced in its

equatorial regions by the unequal distribution of heat there present, and depending principally on its diurnal motion.

These recent and beautiful discoveries show, in the most striking manner, that the operations of nature are more extraordinary, and indicate more of simplicity and wisdom of design in proportion as they are better understood. By what simple expedients, when known, are those wonderful phenomena of the earth's electricity and magnetism produced, which formerly appeared so anomalous and perplexing! And what encouragement do these discoveries hold out to us, with respect to future discoveries, that may throw still further light upon the operations of the Great Architect of the universe.

Of the Distribution of Light in the decomposed Form over the Globe. Every one is familiar with the general fact, that the most splendid exhibitions of colours of every description are displayed in the warmer climates; and that the tints of natural objects, generally speaking, become more sad and faded as we approach the colder regions, till they merge into the white of the polar snows. Most persons, also, are aware of the well known circumstances attending the total abstraction of light from plants and animals, and that they thus become more or less white or *etiolated*. Hence, we need scarcely do more than remind the reader, of what must be already familiar to him, viz., that the decided colours of tropical productions of every kind, whether we consider the gaudy plumage of the birds, of the variegated adornment of the fishes and insects, &c., are so striking, as to be quite characteristic of these productions. In the higher latitudes, also, where the contrast between the summer and winter seasons is very great, the colours of some animals vary with the seasons; being in the summer generally of some dark hue, but in the winter nearly white; while still further, in the polar regions all is more or less white, and the natural covering of the earth, the snow, is the whitest body in nature. Putting out of sight the great importance of the colours of objects, which will fall more naturally to be spoken of hereafter; it may be remarked here, that colours have usually been considered as offering to us one of the most striking instances of the benevolence of the Deity. Colours are universally agreeable to mankind; and the most incurious and ignorant are attracted by, and delighted with, showy exhibitions of them. Now, all this pleasure is the gratuitous gift of the Creator, and places his benevolence in the strongest possible point of view. There was no reason why man should have distinguished colours at all, much less have been delighted with them: but what is the fact? not only are we gifted with organs exquisitely sensible to the beauty of colours; but, as if solely to gratify this feeling, the whole of nature, from

the highest to the lowest of her productions, forms one gorgeously coloured picture, in which every possible tint is contrasted or associated in every possible manner. Is there a human being who can witness the splendid colouring of the atmosphere above him by the setting sun ; who can witness the beauty and endless variety of tint displayed by every object of the landscape around him, down to the minutest insect or flower or pebble at his feet ; who is conscious of the pleasure he derives from these objects, and who reflects that this pleasure was not necessary to his existence, and might have been withheld ? Is there we ask, a human being who duly considers all these things, and who will dare to assert that the Being who made them all is not benevolent ?

3. *Of the Laws of Absorption, Radiation, and Reflection of Heat and Light.*—These laws as applied to the earth generally, are at present but very imperfectly understood. The following remarks will serve to convey some idea of the little we know on the subject.

The reader will bear in mind what was formerly stated, that the absorbing power of bodies with respect to heat (and perhaps light also) is *directly* as their radiating power, and *inversely* as their reflecting power. Such is the general opinion ; and, as far as solar heat and light are concerned, this opinion appears to be well founded ; but we shall see presently that there are strong reasons for suspecting that the radiating power does not always follow the same law as the absorbing power. In the mean time, however, we shall proceed to state what has been advanced on these points.

Mr. Daniell has attempted to show that the absorption and radiation of solar heat increase as we proceed from the equator toward the poles. Thus, in a tropical climate, and under a vertical sun, the greatest extent of the difference between two thermometers, the one covered with black wool, and exposed to the direct rays of the sun, in order that it may absorb to the utmost the incident heat, and the other, uncovered in the shade, is no more than about 47° ; while two thermometers, similarly circumstanced, in the middle of summer, in London, give a difference of 65° ; and in the Arctic regions the difference often amounts to 90° at least : so that in the Arctic regions there is twice as much heat and light absorbed under similar circumstances, as there is in the tropical regions. The same gentleman has also attempted to show (what might have been inferred indeed from the assumed relation between the absorption and radiation of heat and light above mentioned), that that the radiation of heat from the earth's surface obeys similar laws ; that is to say, that the quantity radiated from the earth increases from the equator toward the poles. Laws somewhat analogous, and which, when they are better un-

derstood, will probably throw much information upon these phenomena, seem to hold with respect to light. Thus we formerly mentioned that when a ray of light falls upon fluids, transparent bodies, or metals, the quantity reflected *increases* with the angle of incidence reckoned from the perpendicular; while the quantity absorbed of course *decreases* in the same proportion: but that on the contrary when a ray falls upon *white opaque* bodies, the quantity reflected *decreases* as the angle of incidence increases; while, of course, the quantity absorbed, *increases* in the like proportion. Hence if heat follows the same law, it is evident that the quantity of heat absorbed by the earth from the solar rays, must *increase* from the equator towards the poles; that is to say, as the angle of their incidence increases, as Mr. Daniell has attempted to show. It is proper, however, to observe that Mr. Daniell's views have been called in question, and that some late observations made in high latitudes do not entirely corroborate them.* We have alluded to the subject merely with the view of drawing the attention of Meteorologists to it as one of great interest and curiosity, and as one by no means at present understood. There is every reason to believe that the absorption (and perhaps the radiation) of heat and light, under some of its modifications, are much influenced by polarization, and consequently by certain angles of incidence and reflection; and that these circumstances, in consequence, have much to do with the distribution of heat and light, particularly in the higher latitudes, where they may exert no small influence upon organized beings. The above observations seem to point to the existence of certain general laws, which no doubt hereafter will be elucidated.

In noticing the influence of different colours on the absorption and reflection of heat and light, we stated that black and dark colours generally absorb most and reflect least; and *vice versa*, that white and light colours, reflect most and absorb least; and we are now come to illustrate this interesting subject, and to consider the following questions.—Why does whiteness prevail in the Polar regions? Why, for instance, is snow white? On the contrary, why are all sorts of dark and decided colours met with in the tropical climates, except whiteness, which is comparatively rare? Might not snow have been black instead of white; which

* We allude here to the observations made in those regions, and given in the appendix to Captain Franklin's Second Journey, by Dr. Richardson, Captain Back, and Lieutenant Kendal. In these observations Dr. R. states that the radiation was much stronger in the spring months, *when the ground was covered with snow*, than in the summer months, when the altitude of the sun was greatest. Dr. R. ascribes this greater radiation to the greater clearness of the air at these seasons, but were there no other reasons?

was just as likely if its colour had been the result of accident? or might not whiteness have been predominant under the equator? Perhaps the best mode of answering these questions, and of placing the subject in a striking view, is to examine what would have been the consequence, if whiteness *had* prevailed under the equator, and blackness at the poles.

As heat and light are supposed to obey nearly the same laws, as far as absorption, radiation, and reflection are concerned, it is obvious that if white had prevailed in the tropical climates, almost all the solar heat and light, instead of being absorbed, would have been reflected. The consequence of this reflection would have been, that the accumulation of heat and the glare of light in the lower regions of the atmosphere, near the surface of the earth, would have been intolerable, and would have rendered these regions quite uninhabitable, at least by the present race of beings. The surface of the earth, also, though it would have been heated slowly, would have been overheated in time; and at length would probably have become so very hot, from its comparatively low radiating powers, that the heat could not have been borne. As it is, the heat and light of the sun are absorbed readily, and as freely given off again by radiation; or perhaps the heat, like the light, is decomposed; and thus the whole is preserved in that comparatively moderate and nicely balanced state, which renders even the hottest parts of the earth inhabitable.

On the other hand let us consider for a moment what would have been the consequences if snow had been black, or in other words, if blackness had prevailed in the Polar regions. In this case, all the little light and heat that reach them would have been absorbed, and the effect would have been darkness, more or less complete. From the rapid melting also of the snow on the least exposure to heat and light, we should have been constantly liable to inundations. Thus the whole of the Polar regions of the earth would have been one dark and dreary void, inaccessible to organic life. But by the present arrangement, all these consequences are obviated. The white snow absorbs a certain portion of light and of heat (by a beautiful provision *more* as the angle of incidence increases?) while so much light is reflected as is useful, and no more.* Thus the adjustment of the colours of bodies to

* The reader will observe that, under ordinary circumstances, *white* reflects most and of course absorbs and radiates *least* solar heat and light; but if the above remarks on light be well-founded, the absorption of light (and heat?) by white bodies *increases* with the angle of incidence. Now, as nothing of this sort is known, or can be well conceived to happen, with respect to radiation, the doubt expressed at the beginning of this section arises, viz., whether under all circumstances, the radiating and absorbing powers of bodies obey similar laws, even as far as the solar rays are con-

the circumstances in which they are placed, constitutes an example of the expedients by which those minor incongruities are obviated, that are necessarily incidental to the modes in which heat and light are distributed over the globe ; and presents altogether one of the most obvious and beautiful instances of design connected with the agency of heat and light.

Lastly, it may be worth while to draw the attention of the reader to the striking contrast displayed between the ponderable and imponderable forms of matter, as to the ease with which they are decomposed, and the modes in which they exist in nature.

We have seen that to preserve the homogeneity and integrity of ponderable bodies, as of water and air, elaborate arrangements have been adopted, evincing the most extraordinary design and wisdom ; because the decomposition or derangement of water and air would at once prove destructive to organized beings. But, to preserve the homogeneity of heat, and particularly of light, no such care is shown, because no such care was particularly necessary. The decompositions of these agencies, therefore, are permitted to take their natural course ; and by an admirable provision, so far are colours, magnetism, &c. from being injurious to us, that they constitute one of the chief sources of our knowledge and happiness !

4. *Of the Conduction of Heat below the Earth's Surface on Land.* The soil, from a few inches to a foot or more below the surface, participates very much in the fluctuations of the surface temperature. In general, perhaps, it may be stated, that the temperature of the surface of the earth is a little above that of the incumbent atmosphere by day, and below it by night ; though much will depend in this respect upon the nature of the soil, on its radiating and conducting powers, and on a multiplicity of other conditions that will readily occur to the reader. At a certain distance, however, below the surface, and varying with the latitude and other circumstances, there must be a determinate stratum, where the temperature is uniform, or nearly so, throughout the year. Experiments on this subject are very limited ; but there is reason to believe, that the temperature of this *invariable stratum* coincides nearly, with the mean annual temperature of the place ; and that its depth below the surface, in different latitudes, varies between forty and eighty feet. The reader need scarcely be reminded, that the well known uniformity of the temperature of cellars and

cerned. The absorption and radiation of heat of low intensity, and unaccompanied by light, seem to depend more upon the nature of the surface than upon colour. It must be admitted, however, that at present a great deal of obscurity hangs over the whole of this subject.

caves, depends chiefly upon the circumstances we are now considering. As an instance of the uniformity of temperature in such places, it may be mentioned, that a thermometer placed in the caves under the observatory in Paris, at a depth of about eighty-five feet below the surface, has, during fifty years, scarcely varied more than a quarter of a degree from 11·82° of the centigrade scale; equal very nearly to 53¼° of Fahrenheit.

A few experiments have been made to determine the variation of the temperature, throughout the year at different depths from the surface, down to the invariable stratum; and the following is a summary of the results, which, perhaps, may be considered as generally applicable to the northern hemisphere.

In the month of August the temperature of the earth goes on decreasing in nearly a uniform manner, from a little below the surface to the stratum of invariable temperature. In the month of September the temperature is nearly uniform to fifteen or twenty feet below the surface; beyond which depth the temperature decreases a little and slowly to the stratum of invariable temperature. During the months of October and November the temperature increases from the surface to the depth of fifteen or twenty feet; and below this point it remains nearly uniform to the invariable stratum. During December, January, and February, the temperature, being at its minimum upon the surface, increases in a manner nearly uniform, downwards to the invariable stratum. During March and April there is a rapid decrease of temperature to the depth of one or two feet; below this depth the temperature decreases less rapidly; and still lower, the temperature increases a little. During the months of May, June, and July, the temperature being at its maximum, at the surface, decreases downwards, but less rapidly and to a greater depth; it then begins to increase a little till it attains the temperature of the invariable stratum. The rapidity and degree, however, with which these changes take place, as well as the changes themselves, appear to fluctuate very considerably not only in different places under the same Isothermal line, but in the same place in different seasons.

Since heat is propagated through the soil by conduction, of course it is propagated in all directions. Hence, it may be supposed to move laterally as well as downwards; and, generally speaking, the temperatures of contiguous spots probably tend to equalize each other. But upon the whole, the influence of the lateral propagation of heat through the solid parts of the earth, must be very limited.

5. *Of the Propagation of Heat and Light below the Earth's Surface in Water.* Water is a very imperfect conductor of heat in the usual acceptation of the term. Thus, almost any degree of

heat may be applied, for a considerable time, to the upper surface of a mass of water, without materially influencing the temperature below; so imperfectly and slowly is heat conducted through this fluid. The process by which heat is communicated through water, we have termed *convection*. When heat is applied to the bottom of a vessel full of this fluid, the portion of the water first heated expands in bulk, and thus becomes specifically lighter; it then rises to the top, carrying with it the newly acquired temperature, while another cold portion, sinking to the bottom, is heated in turn, and so on, till the whole mass becomes uniformly heated.

With respect to the propagation of light through water, it has been calculated that not a tenth part of the incident light can advance five fathoms downwards in the most translucent water; that even of vertical rays, one half is lost in the first seventeen feet, and that they become reduced to one-fourth by traversing thirty-four feet, which correspond to the mass of an atmosphere. It thus follows, that only the hundred thousandth part of the vertical rays can penetrate below forty-seven fathoms, which is scarcely equal to the glimmer of twilight; and that the depths of the ocean must be always in perpetual darkness.*

Such are the general principles by which heat and light are propagated in water. But in speaking of this fluid in a former chapter, we alluded to one of the physical properties of water, of the utmost importance in the economy of nature, and which, perhaps, almost more than anything else, indicates design; since, like the composition of the atmosphere, this property of water constitutes an exception, as it were, to a general law, expressly directed to a particular object. We have mentioned that it is a general law, that all bodies, in every state of aggregation, expand by heat and contract by cold; now water forms a marked exception to this law. Like other bodies, water continues to contract on the removal of heat, till its temperature comes down to within a certain distance (7° or 8°) from its freezing point. At this distance, water begins again to expand, and the expansion continues till it becomes ice; at which moment of freezing, a sudden and considerable expansion takes place. Hence, the specific gravity of ice is decidedly less than that of water, and the solid necessarily swims on the surface of the fluid. The importance of this anomalous property of water is so great, that it is doubtful whether the present order of nature could have existed without it, even although everything else in the world had remained the same. For instance, were it not for the comparative lightness of ice, this solid, instead of beginning to be formed at the *surface*

* Article Climate, in the Encyclopædia Britannica.

of water, would have begun to be formed at the *bottom;* as the colder water from its greater specific gravity would naturally have sunk: for similar reasons, also, the lowest stratum of ice would have been the last to have melted. Now, let us reflect for a moment upon the consequences of such an arrangement. In the northern and indeed even in temperate climates, the bottoms of all lakes and deep waters would have been a mass of ice, and totally inaccessible, therefore, to organized beings. During the summer a few feet of the upper part of the ice, would, perhaps, have been melted; but what little had thus become melted in summer, would again have become solid during winter; and as the accumulations of ice would have been constant, all the seas, even perhaps to the tropical climates, at least at their bottom, would, long before this time, have been a mass of ice! But what in reality happens? In consequence of the above anomalous properties of water, this mischief is entirely prevented, and not a particle of ice can be formed in a lake or other collection of water, till the whole mass is cooled down to the temperature of 40°, at which temperature the specific gravity of water is at its maximum.

These properties of water operate in the following manner. On the application of cold to the surface of water, the cooled portion sinks, and its descent forces up a portion of warmer water to the surface, which after communicating some of its heat to the superincumbent air, sinks in its turn; and this process goes on for a greater or less time according to the depth of the water. If the depth be not very considerable, the whole body of water becomes cooled down to 40°; at which temperature the specific gravity not increasing, the circulation ceases, and the *surface* of the water, (not the *bottom*) becomes at length so far cooled as to be covered with ice. If the depth of the water be considerable, the application of cold may be long continued without the result of freezing; hence, in this and in other countries, not intensely cold, it often happens that deep lakes remain unfrozen during the coldest winters.

The above anomalous properties of the expansion of water and its consequences, have always struck us as presenting the most remarkable instance of design in the whole order of nature—an instance of something done expressly and almost (could we indeed conceive such a thing of the Deity), at second thought, to accomplish a particular object. Further, if in conjunction with this anomalous property of water, we take into account the still more anomalous constitution of atmospheric air, and at the same time consider the relations of water and air to organic existence, we are unavoidably driven to the conclusion, that the Maker of water and of air has designedly created these anomalies, to obviate dif-

ficulties which would have rendered organic existence a physical impossibility. Thus, had means not been taken to secure the fluidity of water under the varying circumstances of temperature in which it is placed; the greater portion of this fluid in the world would long ago have been a solid mass of ice, and consequently inaccessible to organic life. Had means not been taken to secure the homogeneity of air at all times, and under all circumstances; this important medium would not only have been constantly liable to local deteriorations; but its properties, long ere now, would have probably become deteriorated to such a degree, as to have rendered the permanence of organic life not less physically impossible. Nor do the suppositions which the sceptic will urge, that these properties of water and air flow naturally from their constitution, diminish the force of the argument. The force of the argument lies, in the first place, in the fact that water and air have been created with such anomalous properties; and, in the next and chief place, *that these anomalous properties have been brought into action precisely where they are required.* Moreover, the argument is greatly strengthened, by the fact that *two anomalies*, rather than that *two ordinary circumstances*, have been thus expressly adjusted.

Having stated the general principles on which heat is distributed through water, and its most remarkable consequence; we are now to enter into a few details with respect to some other consequences of this distribution. Of these one of the most striking is, that the temperature of the water at the bottoms of deep lakes or inland seas, must remain nearly uniform during the whole year. Thus it has been found that the temperature of the water at the bottoms of many of the lakes in Switzerland often varies no more than 3° or 4°, while the temperature of the surface often varies 20° or 30°. Hence in deep waters, in temperate climates, the changes of temperature are chiefly confined to the upper strata of the water; nor can ice (except from some very sudden and powerful accessions of frost) form on the surface of such a lake, till, as before observed, the whole of the water in it is cooled down to 40°, at which temperature all circulation ceases. When a coat of ice has been once formed, this ice, as we shall see presently, has also a powerful tendency to prevent the further cooling of the inferior strata.

With respect to *waters in motion*, as small streams, or rivers of no great depth and magnitude, and containing fresh waters; though unfavourably circumstanced for freezing, they do nevertheless congeal. The process usually commences at the shores where the water is shallowest, and its motion is least rapid; from whence the ice gradually advances towards the centre of the stream. When the whole of the surface has once become fixed,

congelation goes on actively, particularly by night. As the thickness of the ice increases, however, the quantity added daily, even supposing the cold to remain the same, gradually diminishes, on account of the bad conducting power of the ice. Hence in a block of ice taken from a river or lake, we may often observe the strata corresponding with the daily, or rather nightly additions, presenting a gradually decreasing series from several inches down to a few lines in thickness.

Of the Temperature of the Waters of the Ocean at great Depths.—Between the Tropics, the temperature of the ocean diminishes with the depth ; in the Polar seas, on the contrary, the temperature augments with the depth. In the temperate seas, comprised between 30° and 70° of latitude, the temperature of the water gradually decreases as the latitude increases, until about the latitude of 70° ; when the temperature begins to rise as before mentioned. Hence about the latitude of 70° there exists a zone or band at which the mean temperature of the ocean is very nearly constant at all depths. The temperatures of particular parts of the ocean, however, have been observed to be much influenced by the depth and extent of the water, particularly in high latitudes.

We have already mentioned the influence of the saline matters of the ocean upon the *freezing point of sea-water*, and we have now to point out the important consequence of this property in the economy of nature. In its natural state sea-water freezes at about 28° or 29°, but when it has been concentrated by previous freezing the congealing point is reduced to 15° or 16° ; while water saturated with salt, it is said, does not freeze at a temperature above 5°. Besides this property of lowering the freezing point of sea-water, the saline matters also increase its specific gravity and its point of maximum density. Hence from these circumstances, and from their immense depth and extent, the waters of the ocean resist freezing still more effectually than even running fresh water, and are indeed rarely frozen, except in latitudes where the most intense cold prevails.

Of the under Currents of the Ocean existing between the Equatorial and Polar Regions.—That the diminished temperature of the waters of the ocean, at great depths near the equator, could not have been acquired in the torrid zone, is evident; nor, on the other hand, could the comparatively high temperature of the waters, at the bottom of the Polar seas, have been acquired in the frigid zone ; at least this high temperature of the Polar seas cannot be caused from without. Hence it has been supposed that there is a constant interchange going on between the waters of the Equatorial, and those of the Polar regions ; though there are considerable difficulties at present as to the means by which this

interchange is effected. These difficulties arise principally from some uncertainty with respect to the point of maximum density of sea-water, which does not appear to be satisfactorily established. Whether in the profound and comparatively quiescent abyss of the ocean, the process of diffusion, or the central heat of the earth formerly alluded to, exert any influence, we have no means of determining. But if a central heat really do exist, its effects must be considerable, particularly within the frigid zone. Whatever be the cause of this approach to uniformity of temperature throughout the waters of the ocean, at great depths all over the globe, its use in the economy of nature, in tending to equalize the distribution of temperature, cannot be questioned ; since it constitutes one of those beautiful provisions by which the difficulties of the distribution of temperature, necessarily incidental to the earth's figure and motions, are obviated ; whilst among the minor circumstances contributing to the same end, may be mentioned the tides and the innumerable superficial currents produced by winds and by other causes which are to be considered elsewhere.

We have alluded, in a former chapter, to *the difference of temperature as depending upon whether the surface be land or sea ;* and perhaps it may not be amiss, in this place, to make a few remarks upon the actual general amount of the differences of temperature, as produced by land and water.

In the middle of oceans, and far from the influence of land, the diurnal change of temperature of the air near the surface of the sea is much less than upon land. Thus, in the equatorial regions the greatest difference between the temperature of the day and that of the night at sea is said to amount to 3° or 4° only ; while upon land the difference often amounts to 9° or 10°. In temperate regions, and particularly in latitudes extending from 25° to 50°, the difference between the maximum and the minimum diurnal range of the thermometer at sea is still very trifling, amounting only to 4° or 6° ; while upon the continents, as for example, at Paris, the range often amounts to 20° or 30°. To these circumstances it is owing that small insular situations, partaking of the character of the surrounding ocean, are much less liable to great diurnal changes than continents ; and hence, in general, they possess more equable climates.

Both by sea and land the minimum temperature takes place about sunrise. The maximum temperature at sea occurs about noon, or very soon after ; while upon land it takes place from two to three hours after noon. Between the tropics the maximum temperature of the air is said to exceed a little that of the surface of the sea. But when the temperatures are observed at short intervals, as for example, every four hours, and all the temperatures are compared, the results are different ; and they seem to show

that even between the tropics the temperature of the surface of the sea is higher than that of the incumbent atmosphere. Between the latitudes of 25° and 50° the air is rarely warmer than the surface of the sea; and in the Polar regions it is very unusual to find the air as warm as the sea; it is in fact almost always colder, and generally very much colder.

As connected with this part of our subject, it may perhaps, before we close, be desirable to offer a few remarks upon *the temperature of natural springs*, and their relation to the mean temperature of the earth at the places where they make their appearance.

Springs discharging large quantities of water, and thus indicating that they come from considerable depths below the surface of the earth, preserve nearly the same temperature during the whole year. In our hemisphere, what little augmentation of temperature springs undergo, is generally in the month of September, while they are coldest in the month of March; though the differences seldom exceed two or three degrees. If we compare the temperature of the springs of any place, with the mean annual temperatnre of that place, we find that there is a near connection between the two, all over the globe. In the torrid zone, however, the mean annual temperature of the air is usually higher by three or four degrees than that of the springs; while in the temperate zone, on the contrary, the springs are warmer than the air. The excess of temperature of springs, as compared with the mean annual temperature, goes on increasing with the latitude; so that, between 60° and 70° of latitude, this excess amounts to from 5° to 7°; a circumstance we shall again have occasion to notice. Other things being the same, the temperature of springs varies considerably according to their copiousness; as a large body of water will be less liable to be influenced by the surrounding soil, than a smaller body of water; and may even, in turn, influence the temperature of the soil itself.

The subject of *thermal springs*, as intimately connected with the history of volcanoes, belongs to the Geologist.

We have thus enumerated the principal circumstances connected with the distribution of temperature upon the surface of the earth, and at such parts below it as are within our reach. We now come to the second great division of the subject of climates; viz., that connected with the atmosphere.

Section II.

Of the Secondary Constituents of Climate immediately connected with the Atmosphere.

The phenomena of the atmosphere originally constituted the proper study of the Meteorologist, and even yet they claim the largest share of his attention. The subject, in all its bearings, is very extensive, and many of the details are imperfectly understood. We shall endeavour to present a brief outline of the principal phenomena under the following heads.—*Of the distribution of heat and of light through the atmosphere, and of the consequences;—of the distribution of water through the atmosphere, and of the phenomena dependent upon this distribution;* and, lastly,—*of the occasional presence of foreign bodies in the atmosphere.*

1. *Of the Distribution of Heat and of Light through the Atmosphere, and of the Consequences.*—Every one is familiar with the general fact of the diminished temperature of the higher regions of our atmosphere; and that in the hottest countries, by ascending a lofty mountain, we encounter, at different heights, every variety of temperature, even to that of perpetual snow, and of the Polar regions. One of the first circumstances, therefore, that claims the attention of the Meteorologist, is the law of *the distribution of sensible heat, or of temperature, through the atmosphere.*

The law of the distribution of temperature through the atmosphere is tolerably uniform, though it is occasionally liable to variations and interruptions, depending upon local differences, and perhaps upon other circumstances, not satisfactorily understood. The mean results of a great number of observations made in different parts of the world appear to show, that for every 100 yards of altitude, Fahrenheit's thermometer sinks one degree. This statement, probably, does not, within moderate limits, differ much from the truth; though some late researches have rendered it probable that while at different heights the rate of the decrease of temperature is uniform, the rate of altitude increases constantly, and according to laws very similar all over the world; that is to say, supposing the first 252 feet are equal to one degree, the second degree will be equal to 255 feet, the third to 258, the fourth to 261, &c.

The causes upon which this great cold of the higher regions depends are chiefly the two following; first, the perfect permeability of the atmosphere to the solar rays, on which account they radiate through it almost without affecting its temperature, till

reaching the earth they exert their utmost force; and secondly the increased capacity for heat which air possesses in proportion as it becomes more rare. From the first of these causes it happens that the temperature of the lower regions of the atmosphere is derived, not immediately from the sun, but from the earth. The earth absorbing the solar heat, recommunicates it to that portion of the atmosphere immediately incumbent on the surface, while all the atmosphere above remains unaffected; for though, from diminished specific gravity, heated air naturally ascends, yet as its capacity for heat at the same time increases, ascending air rapidly loses its sensible heat: as in the second place we have to explain.

Dr. Dalton, and afterwards Sir John Leslie more completely, have attempted to show that the equilibrium of heat in the atmosphere is obtained *when each of its molecules*, or in other words, *when the same weight of air, in the same perpendicular column, is possessed of the same quantity of heat.* Now, since atmospheric pressure diminishes with the height according to a certain law, it is obvious that the *same weights of air* at the surface of the earth, and in the higher regions, will occupy *very different spaces.* But since the absolute quantity of heat is exactly the same in both portions, it is likewise obvious that in the higher regions of the atmosphere, from the increased capacity of the air for heat, the quantity of latent heat is gradually augmented, while the quantity remaining sensible, becomes less. Hence the temperature of the air diminishes as we ascend, exactly in the proportion that its latent heat, that is to say, its capacity for heat as produced by rarefaction, increases. In consequence of this arrangement, to use the words of Dr. Thomson, "if a quantity of cold air were suddenly transported from an elevated region to the surface of the sea, its density would be continually increasing during its descent, while its latent heat would diminish in the same proportion; and when it reached the level of the sea its temperature would be just as high as that of other portions of air in the same latitude and elevation. Air, therefore, does not feel cold in consequence of falling from an elevated situation, though this be an opinion commonly entertained, but in consequence of its being suddenly transported from a more northerly to a more southerly situation."* Thus, to the above beautiful and simple law, we owe the permanent state of equilibrium of temperature in the atmosphere; for, in spite of all the disturbances constantly produced by minor causes, this equilibrium, from the natural tendency to right itself, is never very seriously affected.

Of the Limits of Perpetual Snow.—Connected with the dimi-

* On heat and electricity, p. 129.

nution of temperature in the higher regions of the atmosphere are the *limits of perpetual snow* in different latitudes. These limits, of course, may be naturally supposed to follow the mean temperature of 32°, from the level of the sea in the Polar regions to the highest point of their range under the equator. This inference is obvious, and, generally speaking, correct; though it is liable to certain modifications, and to some anomalies, of which the following are the most remarkable.

Under the equator the limits of perpetual snow are the most fixed and steady, and seem to exist generally at an altitude of between 15,000 and 16,000 feet. As we recede from the equator, the oscillations for the most part become more striking, and all the phenomena assume a more irregular form. Such, for example, is the case in the Mexican Cordilleras; but still more evidently in the Himmala range, where there is a difference of no less than 4000 feet between the limits of perpetual snow on the northern and on the southern sides of the mountain, that on the northern being the highest. As we proceed towards the temperate zones, we find, in mountainous countries, below the limits of perpetual snow, immense bodies of ice, or *glaciers*, as they are termed. These glaciers are formed by the alternate melting and congealing of the extensive beds of snow that lie above them. The glaciers, accumulating in valleys, are often by the enormous and increasing weight of the snow and ice in the upper parts, pressed downwards far beyond the limits of the snow itself. Such are the *glaciers* of Switzerland, of Norway, and of other countries in temperate climates. All these circumstances, with others that might be mentioned, and many probably that are unknown to us, combine to render the limits of perpetual snow irregular. These irregularities are so great, that Humboldt has given as a mean of many observations, that at the equator the limits of perpetual snow are nearly 3° above the freezing point, while in the temperate zone they are nearly 5° below that point, and in the frigid zone no less than 10° or 11° below freezing; which observations seem to prove that the general temperature of the air decreases in the equatorial, otherwise than in the colder regions. From the peculiar distribution of the land in the southern hemisphere, little is known of the line of perpetual snow in that part of the world; but it will probably be found to be different from that in the north, and generally lower.

The perpetual snow resting on the tops of mountains constitutes a most important provision in the economy of nature, particularly in the warmer climates, where the accumulated snow becomes the prolific source of innumerable rivers without which those regions would be uninhabitable.

There is a striking difference between the elevated and the

lower regions, which must have considerable influence upon organization, though this influence has not been studied so carefully as it ought to be; viz., the difference of atmospheric pressure. At the surface of the earth, the atmospheric pressure is nearly the same in all latitudes, but as we ascend above the surface, the pressure rapidly diminishes. Everything else, therefore, being supposed to be the same, the difference of pressure is probably alone sufficient materially to influence organization, and to render certain provisions and accommodations necessary, of which, at present, we are ignorant; but which might be doubtless much elucidated by a careful study of Alpine plants and animals, as compared with those that occupy the plains.

Of the Distribution of Heat and Light through the Atmosphere in their latent and decomposed Forms.—In the preceding paragraphs we have alluded to the quantity of heat existing *latent* in the higher regions of the atmosphere. But besides this quantity, which may be supposed to be common to the whole atmosphere, the distribution of latent heat and light must in some degree follow the same law as that of sensible heat and light; that is, must decrease from the equator toward the poles. Thus there can be no doubt, that the expanded air of the equatorial regions contains much more heat and light in the latent state, than the comparatively dense and dry atmospheric air of the Polar regions; and it is probable that the rigours of each extreme are mitigated by this provision. The distribution of electricity through the atmosphere seems also to be regulated by very similar laws. It may, however, be remarked that the effects of heat and light, in the latent and decomposed forms, are much more striking as connected with the water in the atmosphere, than with the constituents of the atmosphere itself. We shall, therefore, defer what we have to say on those subjects till we speak of the water in the atmosphere.

Of the Propagation of Sensible Heat through the Atmosphere.—As the diffusion of gaseous bodies through each other is so far a mechanical process that it is regulated solely by the relations of their specific gravities, it follows that under the same pressure, different portions of the same gas, having different temperatures, and consequently different specific gravities, will have a similar tendency to diffusion. Hence, independently of all other circumstances, the warm and light air of the equatorial regions has a natural tendency to diffuse itself toward the poles; while the colder and heavier air of the poles possesses a similar tendency to diffuse itself towards the equator, though in a greatly mitigated degree. The exact amount of these tendencies we have no means of estimating, but they, doubtless, exert considerable influence; and, as the diffusive power may happen to coincide with, or oppose the atmospheric currents, to be next considered, it may augment or diminish their effects.

Though diffusion be thus largely concerned in the lateral propagation of temperature through the atmosphere, this propagation is evidently affected to a much greater extent by the process termed *convection*. Convection, like diffusion, of course, implies motion or currents; which currents as existing in the atmosphere, we need scarcely observe, are denominated *Winds*. The winds, therefore, are of the utmost importance in the economy of nature, as tending to equalize the distribution of temperature over the globe; and the following brief explanation will serve to give a general knowledge of their nature.

Atmospheric currents may be considered under two heads: those of a general kind, and which extend more or less over the whole globe; and those depending upon various transient derangements of the distribution of temperature, the effects of which are limited to particular localities. On each of these we shall make a few remarks.

The *general currents* of the atmosphere depend principally upon the two following circumstances, which, if borne in mind by the reader, will furnish him with a clue to the whole subject: viz., the unequal temperature of the equator and of the poles; and the diurnal motion of the earth upon its axis. The convective operation of the first of these general causes may be thus illustrated. We have stated that the entire pressure of the atmosphere all over the earth's surface is nearly the same, and equal to that of a column of mercury about thirty inches in height. We have also stated that the mean temperature of this atmosphere near the equator, and at the level of the sea is upwards of 80°, while in the Polar regions it is constantly below 32°, the freezing point of water. Hence, as air expands by heat, and becomes specifically lighter, it is obvious that a given bulk of air at the level of the sea round the poles, must be considerably heavier than a similar bulk of air at the level of the sea under the equator. The air, therefore, round the poles being colder and heavier, will have a tendency to flow along the earth's surface from the poles towards the equator, and to displace the lighter air under the equator; while the equatorial air so displaced, will, owing to its lightness, ascend and flow back again over the colder air, north and south toward the poles, so as to preserve the equilibrium. Moreover these currents will be perpetual; for the heat of the equator and the cold of the poles being constant, the same tendency to change will always exist, and thus the currents will be constant likewise.

These atmospheric currents constitute one primary element of the winds, and are the grand means by which the equalization of temperature over the globe is effected. If the earth were at rest, and its surface free from irregularity, these currents or winds would, of course, be in the northern hemisphere always due north, and

in the southern hemisphere due south ; while the velocity would in each case gradually diminish from the poles towards the equator, where there would be a perpetual calm.

But the earth is in a constant state of motion upon its axis from west to east, by which motion the currents are deflected from their northern and southern course towards the east; and this eastern deflection constitutes the other primary element of the winds to be next considered.

On the surface of a globe revolving like the earth on its axis, the general reader will bear in mind that the motion of any given point at the equator is the *greatest*, and at the poles the *least* possible. Thus while the poles are quiescent, the velocity of any given place at the equator of our earth, is about 1000 miles an hour ; from which extreme, the velocity gradually diminishes toward the poles. This motion of the earth on its axis operates in the production of an easterly current in the atmosphere as follows. Supposing there were no atmospheric currents from the north and south towards the equator, and that the earth revolved upon its axis as at present, one of two things must happen. Either the earth during its revolution would carry with it the incumbent atmosphere ; in which case there would be a perpetual calm over its surface : or the earth would revolve within the atmosphere, leaving, as it were, the atmosphere behind it ; in which case there would be an apparent current or wind over the whole of the earth's surface, in a direction opposite to that of the earth's motion, that is from east to west ; which wind, supposing the atmosphere did not move with the earth, would, of course, be at its maximum at the equator. Now both these causes are continually operating, and give origin to all the variety of the eastern currents upon the earth's surface, which, with the northern and southern currents, before described, conspire to produce the well known currents called *the trade winds*. Before we attempt to explain the trade winds, their phenomena may be thus briefly described.

The trade winds in the Atlantic ocean extend to about 28° on each side of the equator. At their extreme northern and southern boundaries these winds generally blow from the east ; but as they proceed towards the equator from the north and from the south, they gradually pass from the east through all the intermediate points of the compass, till near the equator they become in the northern hemisphere, due north, and in the southern hemisphere due south. The trade winds are subject to some slight variations chiefly arising from the position of the earth with respect to the sun. On these variations we do not think it necessary to enlarge. The general phenomena are as we have stated them, and they, upon the principles advanced, appear to admit of the following explanation :

In the temperate regions of the earth the winds seem to obey no certain laws; at least laws so determinate as those of the trade winds. But about the tropics, both in the northern and in the southern hemispheres, the operation of the double currents and motions before described, becomes distinctly perceptible. Thus about the tropics, the surface of the earth begins to move faster than the incumbent atmosphere; and hence in these regions, the prevailing currents are from the east. Indeed near the tropics the currents are nearly due east, principally on account of the great and somewhat sudden change of temperature produced by the vertical sun of the tropical regions; which may be supposed to interfere with, and perhaps to check momentarily, the regular progress of the great northern and southern currents. As we proceed, however, towards the equator, in both hemispheres, the atmosphere gradually acquires the velocity of the earth, while the intensity of the eastern current diminishes in the same proportion, and at length entirely disappears. At the same time the currents from the north and the south continuing, slowly deflect the currents, from the east towards the north in the northern hemisphere, and from the east towards the south in the southern hemisphere, till left alone by themselves the polar currents proceed onward to the equator, as if the motion of the earth had no existence.

The first clear and satisfactory theory of the great atmospheric currents or winds was given, we believe, by Mr. Daniell. The theory of the winds was subsequently illustrated by Captain Basil Hall, in his interesting essay on the trade winds, to which for details we must refer the reader.* Before we quit this subject we may remark that Mr. Daniell traces to these great currents the fluctuations of the barometer, and all the innumerable modifications peculiar to different localities of sea and land, of mountain and plain. For, as he justly observes, in the nicely balanced state of the forces producing these currents, slight irregularities of temperature are capable of causing great disturbances; and expansions and contractions acting unequally upon the antagonist currents, operate by deranging the adjustment of their several velocities. Hence accumulations in some parts, and corresponding deficiencies in others, necessarily arise; and occasion fluctuations in the barometer, far surpassing what would be occasioned by the whole vapour, supposing it were at once added or annihilated. At the same time these irregular distributions, in seeking to regain the proper level, and in struggling to restore the equilibrium, produce temporary and variable winds, which modify the regular currents and often reverse their courses, particularly in the temperate

* See Meteorological Essays and Observations, by J. F. Daniell, Esq., Professor of Chemistry in King's College, &c., page 465, second edition.

regions; where, as formerly mentioned, the alternations of temperature, and the fluctuations of the barometer, are the most remarkable.

Such are the elements of the general currents pervading our atmosphere, and such the modes in which these currents obviate extreme temperatures and their consequences. The same causes are constantly operating in different forms and degrees, so as to produce all the infinite variety among the winds, which we observe in nature. These are so numerous and diversified, as actually to baffle all attempts at explanation or arrangement; we shall therefore content ourselves with one instance only, by way of illustration, viz., *the sea and land breezes.*

The explanation of what are denominated the sea and land breezes is very obvious, and is not less applicable to many similar phenomena. During the day, the surface of the land acquiring heat, imparts its temperature to the incumbent air. This air expanding in bulk becomes specifically lighter, and rises in consequence; while the cooler air from the surrounding sea rushes in to supply its place, and thus produces the current called the *sea breeze.* During the night, on the contrary, the waters of the ocean part with their heat much more slowly than the land, and the reverse action, or the *land breeze* takes place. In hot climates near the sea-shore, and in insular situations, these alternations constitute a most agreeable variety.

2. *Of the Presence of Water in the Atmosphere.*—In the foregoing section we have endeavoured to give an outline of the beautiful provisions that have been adopted to prevent, by means of the air of the atmosphere, the consequences necessarily arising from the unequal distribution of heat and light over the globe. We now come to another subject of not less importance, viz., the phenomena depending upon the existence of water in the atmosphere, and which, taken together, principally constitute what we emphatically denominate *the Weather.*

Of the Relations of the Water in the Atmosphere to Temperature.—We have before stated the fact, that water has a tendency to assume the elastic form at all temperatures. From the tendency of water, thus to rise "above the Firmament," not only the ocean, but ice and snow, are unceasingly contributing their supply of moisture to the air; and this important fluid, so indispensable to vegetable and animal existence, is distributed over the surface of the whole earth. In considering, therefore the relations of the water of the atmosphere to temperature, the phenomena which first claim our attention, are the processes by which water is taken up and again separated from the atmosphere; that is to say, the processes of *Evaporation* and *Condensation.*

In treating of the nature of *Evaporation*, the questions to be

answered at the outset are,—Why is moisture present in the atmosphere? By what force is its presence determined, and its quantity limited? The reply to these questions depends upon the properties of matter in general, and of vapour in particular, as formerly described; which, if the reader bears in mind, will enable him readily to understand what follows.

When water is exposed to the air in an open vessel, the molecules of its uppermost or superficial stratum, being released from the influence of those below them, have a natural tendency to assume that degree of polarity which is appropriate to their temperature. Hence, after acquiring the latent heat necessary to produce this polarity, either at the expense of a portion of their own sensible heat, or that of the atmosphere, the superficial molecules of water become self-repulsive, and fly off into space in the form of vapour. If the space over the water be circumscribed and be a vacuum, the molecules fly off with such rapidity as instantaneously to fill it. But, if the space be occupied by air, or be of indefinite magnitude, the molecules fly off more slowly, so as gradually to diffuse themselves through the whole space; quite on the same principle, and in the same manner, that one gaseous body is diffused through another.

Such, in few words, may be deemed a simple statement of what evaporation is. We shall next proceed to inquire into the nature and operation of the means by which evaporation not only takes place, but is limited within certain boundaries.

In a former chapter, we remarked, that the elastic force exerted by all bodies in the gaseous state bears a certain relation to their temperature, but that the degree of this elastic force varies according to other circumstances; particularly according to whether the gaseous body, at the given temperature, be capable of existing in the fluid or in the solid states, as well as in the gaseous state. Thus, atmospheric air, at the temperature of 32° (and indeed at all known temperatures), is a gaseous body, and, under ordinary circumstances, exerts an elastic force equal to the weight of a column of mercury 30 inches high; whereas, at the same temperature of 32°, water is a solid, and the force of the elasticity of its vapour is not more than equal to about 1-5th of an inch of mercury. But at, and above 212°, its boiling point, water, under ordinary circumstances, can exist only as a gas; and in this gaseous form, and at the temperature of 212°, water obeys precisely the same laws, and exerts the same elastic force as atmospheric air would do under similar circumstances. Hence it will be readily understood, that the law of the elastic force of vapour below 212°, is very different from the law of that force above 212°; as by experiment is found to be the fact.

From the preceding remarks it will appear that, all other things

being the same, the tendency of water to assume the form of vapour, or the rate of its evaporation, as well as the actual quantity of water in the state of vapour in the atmosphere, will increase as the temperature increases. The exact law of this increase, in all its details, we need not state. It is sufficient for our purpose to observe, that at all temperatures below the boiling point of water, that is to say, at all common atmospheric temperatures, while the rate of the increase of temperature is *slow* and uniform, or in an *arithmetical* progression, the corresponding rate of the elastic force of vapour, by which the quantity of water as vapour is determined, increases much more *rapidly*, or nearly in a *geometrical* progression. This important fact is connected with several most interesting circumstances.

The phenomena of the *Condensation* of vapour from the atmosphere, are next to be explained. As the quantity of water in solution in the atmosphere can never be greater, though it may be less, than the quantity proper to the temperature; when vapour (or what is the same thing, when a portion of air saturated with vapour), at any given temperature, is cooled below the point of saturation; a portion of the vapour is separated in the form of fluid water, while the remainder assumes the elastic condition proper to the newly acquired and diminished temperature. The forms assumed by the water so separated are various, and depend very much upon the quantity separated, and on the separation taking place in atmospheric air. When the quantity of water separated is small, the minute detached particles diffused through a large space, are suspended in the atmosphere by its buoyancy, and assume the form of what, for the sake of distinction, we shall call *Visible Vapour*, viz. mists, clouds, &c. When the quantity separated is greater, the particles collect into drops too large to be upheld by atmospheric buoyancy, and they fall to the earth in the shape of rain, hail, &c.

Of the two great processes of evaporation and condensation, it may be further remarked, that by a beautiful provision, they have a constant tendency to limit each its own operations; evaporation is increased by heat and produces cold; condensation is produced by cold and liberates heat. Moreover, in virtue of another wonderful arrangement, by evaporation, water is separated entirely from all foreign bodies, and is thus condensed in a state of absolute purity.

We now come more particularly to consider the subject of the vapour of the atmosphere. To facilitate the understanding of this, we shall, in the first place, suppose the air to be absent, and shall inquire what would be the conditions *of an atmosphere of vapour*, under the pressure and temperature existing at the surface of the earth, and at different heights above the earth's surface.

As the elastic force of vapour increases faster than the tempe-

rature of the vapour; and as the mean temperature at the Equator is, at least, 80°, and that at the Poles below 32° ; it follows, that in an atmosphere of vapour, heated similarly to that of our earth, the specific gravity of the vapour at the Equator, would greatly exceed the specific gravity of the vapour at the Poles. Vapour thus exhibits a condition directly opposite to that of air, under the same circumstances. Hence the tendencies of the currents, and of diffusion, in an atmosphere of vapour, at the surface of the earth, would be precisely the reverse of those in an atmosphere of air; the tendency of the currents would be from the Equator toward the Poles, while the tendency of diffusion would be from the Poles toward the Equator.*

We have elsewhere stated the law of the decrease of the temperature of the atmosphere, observed in ascending from the surface of the earth ; the atmospheric air being supposed to be free from moisture. A similar law would regulate the decrease of temperature in an atmosphere of vapour; but the rate of decrease would be much more slow than in an atmosphere of perfectly dry air. Thus under the Equator, where, at the level of the sea, the mean temperature is at least 80, the temperature of an atmosphere of perfectly dry air would sink to the freezing point at a height of 15,000 feet; while the temperature of an atmosphere of vapour would, at the same height, sink only to 70°. At all the parallels of lower mean temperature, onward to the lowest round the Poles, at any height above the level of the sea, similar differences would exist between the temperature of an atmosphere of perfectly dry air and the temperature of an atmosphere of vapour; these differences, of course, varying with the mean surface temperature. At the same time, throughout the whole range, from the Equator to the Poles, the specific gravity of the vapour at the level of the sea would always exceed its specific gravity at any height above. Hence, in an atmosphere of vapour, there would be no vertical currents; but there would be a strong tendency to diffusion from above downwards ; while the tendency to lateral diffusion, would, at all heights, be nearly the same as at the surface, or would be quite contrary to what would hold in an atmosphere of perfectly dry air.

* We may here observe, once for all, that our former remarks on the diffusion of air of different temperatures, and our remarks now on the similar diffusion of vapour, are inferences only from the general law of diffusion ; and that the diffusion of such fluids has not, at least in so far as we know, been yet the subject of experiment. We do not, therefore, think it necessary to dwell on the precise law of this diffusion. Our remarks have been chiefly made with the view of drawing the attention of philosophers toward these interesting phenomena. The diffusion of gases and of vapour, taken in conjunction with the diffusion or radiation of imponderable matters, would form a noble field to those competent for such physical inquiry.

Having thus stated the leading properties of an atmosphere of air and of an atmosphere of vapour separately, we come to the proper subject of our inquiry; viz., *the condition of an atmosphere resulting from a mixture of air and vapour*—of such an atmosphere, indeed, as that in which we actually live.

The reader will have no difficulty in understanding the nature of a mixed atmosphere, provided he has clearly apprehended what has been above stated, regarding the simple atmospheres which are its components, and will advert to two other circumstances that are now to be noticed. These two circumstances are intimately connected with the principles previously stated, and with each other; and an exposition of them is absolutely necessary for obtaining a true knowledge of the relations of an atmosphere of vapour with an atmosphere of air. These circumstances have not been mentioned sooner, the consideration of them having been intentionally delayed, in order that their influence might be seen, where their application is more immediately requisite. They are as follow.

When vapour and air are mixed together, the resulting volume of the mixture depends on the *amount of the elastic forces* of the vapour and of the air; not on any relation between their volumes. Thus when a cubic foot of air at the temperature of 32°, and exerting an elastic force equal to 30 inches of mercury, is mixed with a cubic foot of vapour, having the same temperature, and exerting an elastic force equal to only 1-5th of an inch of mercury; the volume of the mixture resulting is not two cubic feet, but only 1·0066 foot. Hence, as the addition of vapour to air adds comparatively little to the bulk of the air, and consequently diminishes only in a trifling degree its specific gravity; the great aerial currents formerly described as pervading the atmosphere, are scarcely affected by the vapour they contain.

When two portions of vapour, having different temperatures, are mingled together; or when a portion of vapour is brought into a state of mixture or contact, with a portion of water, or with any other body colder than the vapour; *the resulting mean temperature*, whatever that may be, is, in both cases, the temperature which regulates the elastic force of the mixture. Now, since the elastic force of vapour increases most rapidly from the temperature of 32° to 212°, the increase being in a geometrical progression, while the increase of the temperature is in an arithmetical progression; it follows, that when two portions of vapour of equal bulk but of different temperatures, are mixed together; or when a portion of vapour is brought into contact with any solid colder body; the resulting mean temperature is always below that requisite to preserve the water in a state of vapour. Hence, such mixture or contact is always followed by a portion of the vapour being condensed into water. In a future part of this section, it will be

necessary to illustrate further this important fact, but a familiar instance may be noticed here. Let us suppose that a pound of water at the temperature of 212°, which being in a state of steam, would occupy a space of about 27 cubic feet, were suddenly brought into mixture with a pound of water at the temperature of 32°: the effect would be an instantaneous condensation of the greater part of the steam into water. For the resulting mean temperature would obviously be far short of 212°, below which temperature the elastic force of vapour most rapidly diminishes. On this property of vapour depends the working of the common steam-engine.

The reader is thus at length prepared to enter on the complicated subject of a mixed atmosphere of vapour and of air.

We have shown that the rate of decrease of the temperature of an atmosphere of vapour, in ascending from the earth's surface, would be very much slower than that of an atmosphere of air. Now since, at all temperatures, the existence of atmospheric air is permanent; while the very existence of vapour is dependent on temperature; it follows, that in a mixed atmosphere of vapour and of air, the quantity of vapour contained in the mixture is regulated solely by the temperature of the air: that is to say, the quantity of vapour present in an aerial atmosphere, can never exceed, though it may be less than, the quantity which is proper to the temperature of the air. If the quantity of vapour in such a mixed atmosphere, be precisely the quantity that is proper to the temperature of the air, such an atmosphere is said to be *saturated* with vapour.

But, neither at the earth's surface, nor at any height above it, can the degree of saturation of a mixed atmosphere of air and vapour, be quite equal to that which is proper to the temperature of the air; and the difference between these two degrees of saturation, augments from above downwards. The cause of this difference may be thus explained. The rate of increase of the temperature of air, from above downward, being in arithmetical progression, and the air being, in a mixed atmosphere, that ingredient which controls the whole mixture; the rate of increase of the tension of the vapour, instead of following the geometrical rate which belongs to it as vapour, is obliged to conform to the arithmetical rate of increase of the temperature of the air. The result of this controlment necessarily is, that the quantity of vapour present in a mixed atmosphere will, at any successive diminution of the height above the surface of the earth, become successively less and less than that which would be required to saturate the air. An example will make this result evident.

At the Equator, as we have said, the temperature of the air, at the height of about 15,000 feet, above the level of the sea, is nearly 32°. Now, for the sake of illustration, let us suppose

this air to be saturated with vapour. From Dr. Dalton's table of the tension or elastic forces of vapour at different temperatures, it appears that the tension of vapour at 32° is equal to the weight of .200 inch of mercury; and that the difference between the tension of vapour at 32° and the tension of vapour at 33°, that is to say, the value of the first term or unit, in our assumed arithmetical series is .007 inch of mercury. Now, the difference between 32° and 80° the mean temperature at the level of the sea under the Equator, is 48°; and supposing each of these 48 degrees to increase in an arithmetical progression, .007 for each degree, the tension for the whole 48 degrees will amount to .336, which added to .200, the tension at 32° gives the tension of .536 inch, as that corresponding to the vapour at 80°, the temperature of the earth's surface under the Equator. But, by Dr. Dalton's same table of tensions, we find that .536 does not represent the proper tension of vapour at 80°, but of vapour at about 61° only. According to this estimate it follows, that at the Equator, while the temperature of the air over the earth's surface is 80°, the point of saturation with vapour is 19° below that temperature. Hence, at the Equator, the air immediately incumbent on the earth's surface must be comparatively very dry. Moreover the cause which has been thus shown to produce the dryness of the Equatorial air, at the earth's surface, must all over the globe exert different degrees of the same influence. *The air, everywhere incumbent on the earth's surface, must, therefore, always be under the point of saturation*;—the relative degree of dryness being highest under the Equator, and gradually diminishing as we recede north or south towards the Poles.*

In such a mixed atmosphere as we have supposed, and as in reality surrounds our globe, if its equilibrium be undisturbed, and if it be at rest; the vapour it contains will have nearly the same tendencies to motion and to diffusion that would exist in such an atmosphere of pure vapour, as we have formerly described. But from the more equal distribution of vapour, when mingled with air, the contrasts between the specific gravities of different portions of vapour, in different parts of the atmosphere, will be much less striking than if the atmosphere consisted of vapour alone. Consequently, the rates of motion and of diffusion, which depend upon such differences of specific gravity, will be less remarkable in a mixed atmosphere, even though saturated with vapour, than they would be in a purely aqueous atmosphere; while in an unsaturated atmo-

* The mathematical reader will observe, that the quantities given in the text are not rigidly accurate, but are intended only for familiar illustration of the principles regulating moisture. The truth is, as has been noticed in the text, in *no part* of a vertical column of a mixed atmosphere, in a condition of equilibrium and at rest, can the air be in a state of saturation. It has been remarked, that the degree of saturation often continues nearly uniform up to a certain point, and then suddenly decreases.

sphere the motions of the vapour must be still more liable to be influenced by the motions of the air, than they would be in an atmosphere of air, at its utmost point of saturation.

Before we close this part of our subject let us reflect for a moment upon the consequences of such a state of comparative dryness of the lower atmosphere next the earth. Over the greater portion of the earth, the air which, during the day at least, is warmed by contact with the earth's surface, and thus becomes lighter, has, as we have observed, a constant tendency to rise into the higher atmosphere. Now, if this air were saturated with vapour, of course, whenever the air by rising became mixed with colder air, its vapour would be more or less condensed, and a cloud would be formed. Hence, if we lived in such an atmosphere, we should be always enveloped in a mist, through which the sun would not be visible. But, by the benevolent arrangement we enjoy, this consequence is so entirely prevented, that, unless under peculiar circumstances, and always for beneficial purposes, the air at the earth's surface is hardly ever saturated with moisture. The air that has been warmed by contact with the earth can, therefore, rise from the surface, without any condensation of its nature within the limits of its point of saturation. Thus, at the Equator, before the air reaches the temperature of 61°, the presumed point of its saturation, it must ascend to the height of 6000 or 7000 feet. At this height its vapour will be condensed, and a cloud will be formed; which may either be precipitated on the spot from which its constituent vapour had risen, or may be transported by the currents of the atmosphere, similarly to refresh a distant country, or may be again dissolved in the air; while under all these contingencies the whole of the lower part of the atmosphere is exempt from mist, and continues perfectly transparent. These operations are unceasingly carried on in our atmosphere, over the whole surface of the earth. Moreover, the very clouds, by giving out their latent heat, and shielding the earth's surface from the direct influence of the sun, produce a still further effect, and have a constant tendency to modify their own formation and existence.

The general result of all the complicated and beautiful machinery connected with the movement of vapour is, that water is incessantly raised into the higher parts of the atmosphere, where it is again condensed in the form of rain, &c. over the whole earth. We have, therefore, in the next place to examine a little more in detail the relations of these two great processes of evaporation and condensation, as they are exhibited in nature.

Of the general Relations of Evaporation and condensation.—The first point in the inquiry that naturally claims our attention, are *the mechanical motions by which the relations between evaporation and condensation are maintained.*

The motions of vapour, in a mixed atmosphere of vapour and air, may be considered as of three kinds: those motions arising from *convection*, in which the vapour is carried along by the air; those motions arising from the tendency of the vapour to recover its dynamical (and thermal) equilibrium, when that equilibrium has been disturbed, and which motions we shall, for distinction, term the *proper motions* of the vapour; and those motions of vapour which are caused by *diffusion*.

In a mixed atmosphere of vapour and air, the motions of the vapour, on the large scale of the operations of nature, are influenced, no doubt, in a very great degree, by the motions of the air. For example, large masses, more or less saturated with vapour, in proportion to their respective temperatures, and having either vertical or lateral motion, must carry with them the vapour they contain, whether there be much or little vapour so contained. On the other hand, motions of the air, on a smaller scale, as we shall presently see, may be even caused—may certainly be accelerated or retarded, according as the proper motion of the vapour, to be next considered, may agree with, or may be opposed to, these motions of the air. When once, however, the vapour in the atmosphere has been separated, and has assumed the form of *visible* vapour, its own proper powers of motion cease, and it becomes entirely subject to those of convection. Visible vapours, therefore, of all kinds, from their being liable to be wafted by every breeze, are in a constant state of motion, and are thus frequently carried where vapour, in virtue of its own tendency to motion, would never reach.

In an atmosphere of vapour, when the temperature, and consequently the elasticity, of any portion is reduced; the surrounding vapour, by virtue of its greater elastic force, continues to advance towards the cooler locality and to be there condensed until the thermal equilibrium is restored. The motion thus arising, which depends upon its dynamical properties, constitutes what we have denominated the *proper motion* of vapour. In an atmosphere of vapour this restoration of the dynamical equilibrium, upon which the thermal equilibrium also depends, would take place with so great rapidity, as to be almost instantaneous. But in a mixed atmosphere, the case is different. In such an atmosphere, the presence of the heavier and more abundant air modifies, in a remarkable degree, the rapid motion of the lighter and less abundant vapour. Hence, instead of a rush of vapour and a momentary deluge, the motions of the vapour take place slowly; and sudden evaporation and condensation, with their consequences, are effectually prevented.

These tendencies to motion, in vapour of different temperatures, have, no doubt, great influence on the contiguous surfaces of large masses of air differently saturated; and, in particular,

are liable to affect smaller masses of air differently saturated, when they are in the immediate neighbourhood of each other. Thus, as we have already noticed, the disturbance of the equilibrium of the vapour may be to such an extent, in some portion of the mixed atmosphere; that the surrounding vapour, urged to move by its tendency to restore the equilibrium, may occasionally be supposed to drag with it the air and the clouds, and thus produce local currents. For instance, let us imagine a mass of warm and almost perfectly dry air to be brought into the neighbourhood of another mass of air of precisely the same temperature, but saturated with vapour. The two masses of air, from being of the same temperature, would, as air, have no tendency to intermingle. But as being portions of a mixed atmosphere of vapour and air, the dryer air would be, as it were, a vacuum, towards which the vapour from the moist air would have a tendency to flow till both masses of air became equally moist. In such a case, the motion of the vapour might be supposed to cause more or less of motion in the air, while a momentary cloud would probably be formed; which cloud would be dissipated when the equilibrium was restored. In this way, it is likely that many of the minor motions of the atmosphere are produced.*

The motions of vapour arising from its *diffusive* powers are quite distinct from those motions of vapour which are controlled by the motions of the air, or by the dynamical tendencies of the vapour itself to recover its condition of thermal equilibrium. These diffusive motions of vapour, as formerly observed, depend on differences between the specific gravities (the absolute quantities of matter) of contiguous and communicating gases, under the same circumstances of pressure and temperature. Though the motions of vapour depending on diffusion may retard, or be retarded by, the other motions to which vapour is liable; in general, there is reason to believe that the motions of vapour by diffusion, in their most decided form, surpass, or take place independently of, all the other motions of vapour, and in this freedom from control, resemble the radiation of imponderable bodies. The laws which diffusion obey have been already stated, and need not be again repeated. These laws may be applied to the consideration of the diffusion of vapour in the following manner.

The diffusive tendencies of an atmosphere of perfectly dry air, and of an atmosphere of vapour, would, as we have seen, at the earth's surface be in opposite directions; the diffusive tendency in the aerial atmosphere, being from the Equator toward the Poles, and that in the aqueous atmosphere being from the Poles

* In all the cases given in the text, the effect of electricity is, for the sake of distinctness, kept out of view.

towards the Equator. The vertical tendencies also of the two atmospheres would be very different. An atmosphere of perfectly dry air, in a state of thermal and dynamical equilibrium, would have no tendency to diffusion; for the colder air in descending, and the warmer air in ascending, by change of bulk, acquire the temperature appropriate to the height. The effect of this change of bulk and acquisition of temperature is, as we have elsewhere stated, such, that if air from any height in the atmosphere were brought to the surface of the earth, it would have precisely the same temperature as the air already incumbent on the surface. But the case is different with vapour, even in the comparatively rare state in which it exists in a mixed atmosphere. We have seen that in an atmosphere of vapour, if the temperature at the surface of the earth were 80°, the temperature at the height of 15,000 feet would be only 70°; while in an atmosphere of perfectly dry air, having a similar surface temperature of 80°, the temperature, at the same height of 15,000 from the surface, would be 32°. Now, as in a mixed atmosphere of vapour and air, the temperature of the air determines that of the vapour; if in such a mixed atmosphere, vapour having the temperature of 32°, were brought from the height of 15,000 feet to the surface, where the temperature is 80°; the temperature of the vapour would, by increased pressure and the consequent evolution of more latent heat, be increased only to about 42°; while, as we have seen, where the temperature of the surface is 80°, the point of saturation of the air with vapour is at least 61°. Hence the specific gravity of vapour from the height of 15,000 feet, when reduced to the same degree of pressure as that at the surface, is found to be much below the specific gravity of that vapour which actually exists at the surface. Consequently, throughout a mixed atmosphere of vapour and air, there is a tendency to vertical diffusion, the predominant tendency being from above downwards. From the extreme tenuity of vapour in the higher regions of the atmosphere, and the great tendency therefore, which that vapour has to diffusion, it is probable that the diffusive motion of the vapour may occasionally have a velocity approaching, as we have said, to that of radiant matter, itself. In this way the rare and cold molecules of water may be supposed to dart, or radiate, as it were, far into the warmer atmosphere before their velocity is arrested. Nay, in the Polar latitudes, the molecules of water, from the higher parts of the atmosphere, may even reach the earth's surface, by shooting, like rays of heat and light, directly through the air, without materially affecting its temperature.

After these general remarks on the motions of vapour, we shall now take a rapid view of the mutual relations of the two great processes of evaporation and condensation.

We have already described the general phenomena of evaporation and condensation, and have stated the laws on which these phenomena depend. It will, therefore, in this place, be sufficient to remind the reader that the degree, and the rate, of evaporation though they increase with the temperature, are regulated chiefly by the existing degree of saturation of the air. That is to say, under all temperatures evaporation decreases, as the air that receives the vapour, approaches its point of saturation. Hence it follows, that in an atmosphere perfectly saturated with moisture, and in a state of thermal and dynamical equilibrium, there can be neither evaporation nor condensation. The processes of evaporation and condensation, therefore, always indicate a disturbance of the thermal equilibrium in some part of the atmosphere : condensation denoting a depression of the temperature below the mean, or point of thermal equilibrium: evaporation, on the contrary, denoting that the temperature in some part of the atmosphere has been raised above the mean ; or at least that the temperature having been depressed below the mean, is again undergoing an elevation to the mean point. Evaporation and condensation may be thus considered as mutually dependent; so that one process cannot take place without the other. For this reason, in the great expanse of nature, these two processes oscillate or fluctuate about the point of equilibrium, within certain limits which are never passed; and which limits, though subject to countless anomalies, in general, decrease from the Equator toward the Poles.

With respect to the temperature which constitutes the point of equilibrium; in an atmosphere of vapour, that point would, of course, be the maximum point of saturation. But in a mixed atmosphere of vapour and air like that of our globe, the point of equilibrium cannot be the point of utmost saturation, but must be that *inferior point of saturation* formerly described, as being determined by the temperature of the predominant air. Thus at the Equator, where the mean temperature at the level of the sea is about 80°, the mean point of saturation will, according to our former estimate, be 61° ; while in London, where the mean annual temperature is about 49½°, the mean point of saturation, (or the *dew point*, as it is termed,) has been fixed by Mr. Daniell at 44½°. In temperate climates, the mean point of saturation at any particular place, varies with the seasons from day to day, being higher in summer than in winter. During any shorter period, as that of a day and night, the mean point of saturation, as might be expected, generally bears a certain relation to the *lowest* degree to which the temperature has fallen during the period ; since the *Hygrometer** shows that the degree of saturation, at any hour, is

* The Hygrometer is an instrument for measuring the degree of mois-

seldom below the point of saturation corresponding to the lowest temperature of the twenty-four hours; at which point it continues nearly uniform, so that the point of saturation during the warmer parts of the day generally varies only a few degrees. The elevation and depression of the dew point in temperate climates is thus another, and unceasing cause of change, and produces a variety in evaporation and condensation so great as to baffle any attempt at accurate inquiry.

From what has been said, it will appear that in a mixed atmosphere, the rate of evaporation and of condensation, other things being equal, will depend, not on the difference of the temperature of the air from the maximum point of saturation, but on the difference of the temperature of the air from that of *the mean dew point;* that is to say, will increase or diminish as this difference increases.

The *accidental* circumstances which principally operate to affect the rate of evaporation, are the greater or less extent of the evaporating surface, and the velocity and degree of saturation of the current of air over that surface. But besides these causes of variation, there are other circumstances which probably have great influence on evaporation; some of which are to us of the utmost interest, as being brought more immediately in contact, as it were, with our existence. The chief of these additional circumstances affecting evaporation which we shall notice, are, *Diffusion;—Circumstances incidental to the Water* which undergoes evaporation; and *Circumstances incidental to the Air* into which the water is evaporated.

By the general arrangement which we formerly considered, it appears that evaporation and condensation diminish from the Equator, onward to the Poles. But since increased temperature, which is the cause of evaporation, predominates at the Equator; while diminished temperature, which is the cause of condensation, predominates at the Poles; it may perhaps be inferred, that generally speaking, evaporation will be relatively greater at the Equator; and, on the other hand, that condensation will be relatively greater at the Poles. In an atmosphere of vapour such unequal effects could not indeed take place; from the rapid nature of the motions which would arise throughout the whole of such an atmosphere, so as instantaneously to restore the equilibrium. But in a mixed atmosphere of vapour and air, the result would be different. If there were an excess of condensation at the Poles; before the corre-

ture of the atmosphere. That of Mr. Daniell is here alluded to, which is the only one that acts upon scientific principles. *Daniell's hygrometer* shows the degree of temperature at which water is deposited from the atmosphere, and consequently its state of saturation.

sponding evaporation could take place at the Equator, innumerable changes would be produced in the atmosphere over all the other parts of the globe intervening between the Equator and the Poles. Further, we shall see presently that much more water is at all times condensed on the land, than is ever evaporated from the land. The excess that is condensed flows off in rivers in warm and temperate climates, and thus accumulation is prevented; but in the Polar regions this outlet is cut off, and the superfluous water would be locked up in the shape of ice. From these circumstances, therefore, and from others that might be noticed, it is not unreasonable to suppose, that in the colder climates, other things being alike, and the arrangements which regulate vapour being alone considered, condensation of water would proceed much more rapidly than its evaporation; and hence that around the Poles there would be a constant accumulation of water in the condition of ice. But we know that there is not any such accumulation, in those parts of the Polar regions which have been explored. It is manifest, therefore, that in these regions the energy of evaporation must be fully equal to that of condensation. It is indeed true, that evaporation goes on very rapidly from snow and ice. Thus Howard mentions an instance in the month of January, in a certain year, when the vapour, from a circular area of snow five inches in diameter, amounted to 150 grains between sunset and sunrise; and before the next evening, 50 grains more were added to the amount, the gauge having been exposed to a smart breeze on the housetop. Under like circumstances an acre of snow would, in the course of twenty-four hours, evaporate the enormous quantity of 64,000,000 grains of moisture! Even by the evaporation during the night only, a thousand gallons of water would, in that short time, be raised from an acre of snow. It may thus be easily understood how a moderate fall of snow may entirely vanish during a succeeding northerly gale, without the slighest perceptible liquefaction on the surface.*

We have given this statement to satisfy the general reader of the fact, that evaporation is constantly going on from snow and ice. But the quantity, great as it appears, does not surpass, or even equal, what it might be supposed to be, on admitted principles. Whether, therefore, evaporation really takes place in a relatively greater degree in the Polar regions, so as to compensate for that portion of the condensed water which is there fixed as ice, but which in warmer climates flows off to the sea, in the form of rivers, remains to be proved; though, to preserve the equilibrium and to prevent accumulations, some such supposition appears to be necessary. Can the difficulty be solved by the aid

* Article Meteorology in the Encyclopedia Metropolitana.

of the principles of *diffusion?* Does not a portion of the attenuated vapour of the Polar latitudes diffuse itself, and penetrate from thence towards the Equator; thus leaving the higher regions of the atmosphere in the Polar latitudes comparatively dry, and the lower portion of the atmosphere more apt for evaporation? And is not this diffusion of moisture from the Poles one of those beautiful expedients, which compensate for the inequalities of evaporation and condensation, and by which these inequalities are obviated?

The circumstances *incidental to water*, and affecting evaporation and saturation, arise chiefly from its purity or impurity. The presence of foreign bodies, as of saline matters, for instance, is well known to raise considerably the boiling point of water; in other words, they lower its tendency to become vapour, and thus diminish its evaporating and saturating powers. Hence the air over the sea, though, of course, much nearer, in general, to the point of saturation appropriate to the latitude and temperature, than air over the land, is comparatively seldom in a state of perfect saturation; and sea-water, so far from being capable of saturating the air with moisture, up to the dew point, has even the power of abstracting a portion of the moisture from an atmosphere so saturated, and of thus, to a certain extent, drying the air.

Evaporation on land is precisely similar to evaporation from sea-water, since the various rocks and soils may be considered as so many saline matters, diminishing, in their several degrees, the tendency to become vapour possessed by the water united with them. Hence, under like circumstances, some rocks and soils are dry, while others are moist; so that, in proportion to the evaporating powers of the rocks and soil of a country, will that country be liable to all the consequences of dryness or of dampness of soil. Plants also seem to differ much in their capacity for retaining water. The dryness of a country will, therefore, be considerably affected by the nature of its vegetation; and the predominance of certain plants or trees in a district may thus increase the dampness of its soil.

Regarding the effect that *foreign matters in the atmosphere* have in influencing evaporation from the subjacent land or water, we are unable to speak with as much confidence, as we have spoken of the controlling power of the foreign matters in the water itself. Many years ago, particular circumstances led us to form the opinion, that a combination of water and oxygen is a frequent, if not a constant, ingredient in the atmosphere. This ingredient, which we suppose to be a vapour, and analogous to (we do not say identical with) the deutoxide of hydrogen, may be the cause of numerous atmospheric phenomena, which at present are very

little understood. Among such phenomena are those of evaporation we are now considering.

The difficulties attending an investigation of the atmosphere, and more than all, the total want of opportunity, have rendered us unable satisfactorily to verify the opinion we have advanced. We have stated the opinion as conjectural only, and in order that the attention of those more fortunately situated may be drawn to so important an inquiry.

When treating of the composition of atmospheric air, we observed that the best analyses almost invariably indicated a slight excess of oxygen above the amount of 20 per cent., which there ought to be in the atmosphere, if its composition were, as there can be little doubt that it is, determined by the laws of chemical proportions. Now this excess of oxygen in the atmosphere, we have every reason to think, becomes periodically associated in some way with the vapour that is also in the atmosphere; and thus not only modifies the properties of the vapour, but at the same time materially influences the rate of evaporation from the earth's surface. This excess of oxygen may operate in the following manner. The vapour in union with oxygen (deutoxide of hydrogen?) ceases, of course, to act as vapour; hence in air saturated with vapour, and as moist as possible, if a portion of the vapour were suddenly to combine with oxygen, the air would as suddenly *appear* to become dry, though in reality it contained the same quantity of water in solution as before. Moreover the rate of evaporation would be increased by such a combination of vapour and oxygen; for its effects, whatever these might be, would be superadded to the ordinary effects of evaporation, and would thus more or less increase the quantity of water converted into vapour.

Oxygen in this state of combination with vapour seems to be particularly grateful, if not necessary to animal life. The air in which it abounds is dry, bracing, and exhilarating, while the predominance of moisture, from its occasional and sudden abstraction, induces the opposite feeling of dulness and listlessness. It is probable that some soils and situations are more favourable than others to its existence, and that places are more or less healthy according as it is present or absent.

The oxygen and vapour in this combination are so feebly associated that they appear to be separated by the slightest cause. Hence the results of every *common* analysis and examination of air are the same nearly as if such a state of combination did not exist. We may mention, however, as corroborative of our opinion, the bleaching qualities of dew and of the air itself, as also the large proportion of oxygen sometimes contained in snow water and in rain water; attention being at the same time directed to the well known bleaching qualities of the deutoxide of hydrogen.

Much more might be said on this curious subject, especially

regarding its relation to the *electricity* of the atmosphere. But as our observations must be in some measure speculative we shall for the present desist.

Of the actual Quantity of Water that is evaporated and condensed over the Globe.—From the principles we have stated it will appear that the quantity of water evaporated and condensed over the globe may be supposed to vary with the mean temperature, and consequently with the latitude. But, from local or other causes, the quantity varies so much, even in the same place, in different years, that the exceptions are more numerous than the instances of the correctness of the rule.

The following table, however, shows the general truth of the supposition, and that the average quantity of rain diminishes from the Equator to the Poles. In fact, a much larger quantity of rain must fall in the Equatorial than in the Polar regions, as is sufficiently proved by the magnitude of the rivers within the Tropics; for the size of the rivers of course depends on the quantity of the rain; the rivers being the conduits along which a certain portion of the precipitated water is borne to the sea.

TABLE.

	Inches.
Uleaborg	13.5
Petersburg	16, 17.5
Paris	19.9
London	*20.7, †22.2, ‡25.2
Edinburgh	22., 24.5, §26.4
Mean of Carlsruhe, Manheim, Stuttgard, Wurtzburg, Augsburg, and Regensburg, (Schow)	25.1
Epping	27.0
Bristol	29.2
England (Dalton's mean)	31.3
Liverpool	34.1
Manchester	36.1
Rome	39.0
Lancaster	39.7
Geneva	42.6
Penzance	44.7
Kendal	53.9
Mean of twenty places in the lower valleys at the base of the Alps	58.5
Great St. Bernard	63.1
Vera Cruz	63.8
Keswick	67.5
Calcutta	81.0
Bombay	82.0
Ceylon	84.3
Adam's Peak, ditto	100.
Coast of Malabar	123.5
Leogane, St. Domingo	150.‖

* Dalton. † Daniell. ‡ Howard. § Adie.

‖ From the Encyclopædia Metropolitana. Article Meteorology, p. 123.

In this table the names of the places to which it refers are arranged progressively, according to the amount of rain that falls in each place ; and though the progression exhibits great irregularities, yet the table fully establishes the general decrease of rain with the increase of distance from the Equator.

Sir John Leslie has shown that if all the aqueous vapour which can at any time be held in solution by the whole atmosphere, were at once precipitated on the earth in the form of rain, it would not be more than about five inches in depth: now as in the course of a year many times this quantity of rain falls from the atmosphere, its replenishment of course must depend upon evaporation; of which evaporation we may thus infer the general amount. With respect to the quantity of rain that descends annually on the entire surface of the earth, we want the means of forming an estimate, though there is no proof that this quantity is subject to any material difference. The distribution indeed, as we have seen, diminishes with the latitude, and varies according to numerous local peculiarities, to some of which we shall hereafter allude. Often also, no doubt for the wisest purposes, the same place is liable to considerable fluctuations in the annual amount of rain, or at least in the times of its precipitation; yet all these variations oscillate within certain limits, and scarcely affect the mean quantity proper to the place; thus showing that the distribution of rain obeys the same laws that regulate the more general and fixed operations of nature.

Of the whole water that is condensed upon the surface of the earth, a certain portion, of course, enters into the soil. The depth to which such water sinks is determined by the declivity of the surface, by the nature of the inferior strata, and by other circumstances; but, after a greater or less period, and range of circulation, it usually again makes its appearance in the open day, in the form of *Springs*. The conjunction of springs and the occasional addition of a portion of rain water, which is neither immediately absorbed by the soil, nor evaporated, constitute brooks and rivulets ; these again uniting in their progress from the higher and interior parts of the countries where this water has been deposited, form the larger rivers, which, after dispensing innumerable benefits to the inhabitants of the plains in their course, finally discharge their superfluous waters into the ocean. As the origin of the superfluous water which flows from the rivers to the ocean is thus, unquestionably, derived from the vapour condensed in the interior of the countries where the rivers originate, it follows, that in every country where there are rivers, *condensation must surpass evaporation.* That is to say, a large proportion of water condensed on the land, must have been evaporated not from the land, but from the neighbouring ocean.

The relative proportions of the water that is condensed, and of the water that is evaporated vary exceedingly in different countries. Such indeed is the amount and variety of the differences that it is impossible to estimate them ; though it is probable that in the same country the proportions are nearly constant; or, at least, that there is a mean proportion about which the differences oscillate within trifling limits. In this country, Dr. Thomson has estimated that, taking the whole of Great Britain together, the mean fall of rain amounts in the course of a year to 36 inches, the dew being included, (which is considered to amount to about four inches) ; and that the quantity of water evaporated is about 32 inches. Consequently, the excess of four inches must be supposed to go to supply the springs and rivers ; and as these four inches are thus not taken up again by evaporation from the land, they must be drawn from the seas that encircle our shores.* These estimates of the water that is condensed and evaporated in Great Britain can only be viewed as rude approximations ; and, even admitting them to be correct, they could scarcely be applied with any advantage to an inquiry into the actual condensation and evaporation in other countries or climates, which in all instances must be determined by observation and experiment.

Having spoken of the accidental circumstances which influence evaporation, we are now, in the last place, to treat of those *accidental circumstances which influence condensation.*

The condensation of vapour from the atmosphere, as we have already stated, differs in some degree, according to the origin of that diminished temperature by which the condensation is produced. We shall, therefore, commence with the phenomena of the precipitation of moisture depending on the *radiation* of heat from the earth's surface ; the most remarkable of these phenomena are *Dew*, *Hoar Frost*, and certain forms of *Mist.*

Of Dew.—The phenomena of dew were first satisfactorily explained by the late Dr. Wells, who showed by the most decisive experiments that, apparently, they were all owing to the effects of the radiation of heat from the earth's surface into space, during the absence of the sun. The reader is referred to Dr. Well's "*Essay on Dew*" for details. It is sufficient for our present purpose to observe, that when the direct influence of the sun is removed in the evening, and the surface of the earth thus no longer continues to acquire heat; at that instant, from the ceaseless activity

* On heat and electricity, p. 266. It is proper to observe, that this estimate differs considerably from a previous estimate of Dr. Dalton, who fixes the proportion of water as flowing off by the rivers, in England and Wales, at thirteen inches. It is probable that the truth lies somewhere between the two estimates.

of heat to maintain a state of equilibrium, the surface of the earth, being the warmer body, radiates a portion of its superfluous temperature into the surrounding space; and thus the air immediately in contact with the surface becomes cooled below the point of saturation, and gives off a portion of its water in the form of dew.

We formerly stated that the radiating powers of bodies differ exceedingly according to their composition, the nature of their surface, their colour, &c. These differences, of course, produce corresponding effects on the deposition of dew; and, as beautifully demonstrated by Dr. Wells, explain its greater or less deposition under certain circumstances, or its entire absence under others. Thus, what formerly appeared so extraordinary, viz. why in the self-same state of the atmosphere, &c. one portion of the earth's surface, or one portion of herbage, should be covered with dew, while another in the immediate neighbourhood should remain dry, is no longer a mystery, but is perfectly explicable on the supposition of their different radiating powers.

The deposition of dew is always most abundant during calm and cloudless nights, and in situations freely exposed to the atmosphere. Whatever interferes in any way with the process of radiation, as might be expected, has a great effect on the deposition of dew. Hence the radiation of heat, and consequently the deposition of dew, is not only obviated by the slightest covering or shelter, as by thin matting, or even muslin; by the neighbourhood of buildings, and innumerable other impediments, near the earth's surface; but matters interposed at a great distance from the earth's surface have precisely the same effect. Thus clouds effectually prevent the radiation of heat from the earth's surface; so that cloudy nights are always warmer than those which are clear, and, in consequence, there is usually on such nights little or no deposition of dew.

From dew there is an insensible transition to *Hoar Frost;* hoar frost being in fact only frozen dew, and indicative of greater cold. We observe, therefore, that frosty nights, like simply dewy nights, are generally still and clear.

The influence of radiation in producing cold at the earth's surface would scarcely be believed by inattentive observers. Often on a calm night, the temperature of a grass plot is 10° or 15° less than that of the air a few feet above it. Hence, as Mr. Daniell has remarked, vegetables, in our climate, are during ten months of the year liable to be exposed at night to a freezing temperature, and even in July and August to a temperature only two or three degrees warmer. Yet, notwithstanding these vicissitudes, in the words of the same gentleman,—"To vegetables growing in climates for which they are originally designed by nature, there can be no doubt that the action of radiation is particularly beneficial,

from the deposition of moisture which it determines upon the foliage ; and it is only to tender plants, artificially trained to resist the rigours of an unnatural situation, that this extra degree of cold proves injurious."* It may be observed also, that trees of lofty growth frequently escape being injured by frost, when plants nearer the ground are quite destroyed.

Such is the explanation of the phenomena of dew now universally admitted, of the general accuracy of which there cannot be the least doubt. But, we may ask, are *all* the phenomena of dew strictly referrible to radiation ? and does not a portion of the water deposited as dew arrive at the earth's surface by diffusion from the higher and colder regions of the atmosphere, as formerly suggested ?

Of Mists and Fogs.—Mists are not necessarily connected with the deposition of dew, because during the deposition of dew the atmosphere often continues transparent, even to the earth's surface. At other times, however, and for reasons which, in the present state of our meteorological knowledge, cannot be satisfactorily explained, the deposition of dew is accompanied by a visible vapour or mist, more or less dense, and extending from the surface of the earth to a greater or less height in the atmosphere. When mists, from other causes, are general, and extend to considerable heights above the earth's surface they acquire the name of *fogs*. The optical properties and the buoyancy in the atmosphere of mists and fogs, would seem to indicate that they are not formed of solid particles, but of minute hollow vesicles, having the quality of mutual repulsion; the tendency to repel each other, preventing the coherence of the vesicles into drops, at least under ordinary circumstances. These vesicles have been occasionally observed of considerable magnitude. Thus Saussure, in one of his Alpine journeys, saw vesicles float slowly before him having greater diameters than peas, and whose coating seemed inconceivably thin. It is proper to mention, however, that there is diversity of opinion respecting the actual constitution of visible vapour.

That the cause of the formation of mists and of fogs is, to a certain extent, similar to that of the formation of dew, appears by their prevalence over rivers and large masses of water, especially during the autumnal months. The radiation of heat from the land and from the water is at these seasons very different ; the difference being greatest when the temperature of the water approaches 40°, its point of maximum density. The water is then of a temperature nearly uniform, both by day and by night, while the temperature of the land is, during the day, much higher than 40° and during the night, often much under that temperature.

* Meteorological Essays and Observations, p. 511, second edition.

The water in most cases occupying the lowest situations; whenever, from the inequalities of the surface of the land, or from any other cause, the colder air produced by radiation over the land, is made to mix itself with the warmer air over the water, the moisture in the warmer air is condensed so as to become mist. Hence the formation of mist differs slightly from that of dew, inasmuch as there is occasionally (not always) an intermixture of air of different temperatures. The reason is thus evident of the fogs and mists so frequently seen over rivers and in valleys, or in other situations where there is a collection of water. The occurrence of these mists is usually on clear and cold nights,—oftener in autumn, and seldom or never in cloudy weather; the state of the atmosphere having exactly the same influence on them, as on the deposition of dew. There cannot be a doubt that these mists, like clouds, produce a great effect in impeding radiation, and in thus mitigating the intensity of cold. Mists are therefore of much importance in the economy of nature. Plants growing in low grounds are by them shielded from the destroying influence of the sudden cold, that would almost certainly be produced, not only by the free radiation of heat in such situations, but by the descent of cold air from the surrounding high grounds.

The fogs that hang over great towns admit of an explanation similar to that of other aqueous fogs. The air of the town being warmer than that of the surrounding country, and being at the same time charged with moisture nearly to the point of saturation, is, in cold weather, suddenly cooled, either by the radiation of its own heat, or by the admixture of the neighbouring cold air; while the superfluous moisture is condensed as a fog.

The fogs of high latitudes, more especially the fogs of the Polar seas, are in the same manner owing to the radiation of heat. The cooling of the warmer air over the immense masses of floating ice, gives rise to an unequal distribution of temperature, and thus at certain seasons, to uninterrupted fogs. In all these instances the effect of fogs is probably beneficial in alleviating the severity of cold by checking great and sudden alternations of temperature, which would otherwise interfere much with the operations of organic life.

Fogs have been sometimes observed of a strong odour, apparently the result of an admixture of foreign bodies. In a subsequent paragraph these fogs will be fully considered.

Of Clouds.—From mists and fogs the transition to clouds is easy and natural; as clouds, in reality, are nothing more or less than masses of visible vapour, precisely similar to that composing fogs, but existing at a distance above the earth's surface. Clouds differ principally from mists and fogs in their mode of formation. Thus mists, like dew, as we have seen, are the re-

sults of the cooling of the lower strata of the atmosphere by radiation. Fogs are so far the result of radiation that they usually arise from the influence that air cooled by radiation, exerts on warmer air. While clouds probably depend altogether on *convection*, and result from the intermixture of strata of air of different temperatures, and in different states of saturation, in the higher regions of the atmosphere.

Such is the general opinion of the formation of clouds ; but it must be confessed that there are considerable difficulties about the subject ; and that the mere assumption of strata of different temperatures, more or less saturated with vapour, and having the proper motions supposed to depend upon such different temperatures and degrees of saturation, seems quite inadequate to account for all the phenomena connected with the formation and appearance of clouds. May not many of the phenomena of clouds depend upon the diffusion of vapour from cold and distant regions ? May not other phenomena result from the more or less sudden decomposition (by electricity ?) of the deutoxide of hydrogen which we conceive to exist in the atmosphere ?

From the principles formerly stated when we described the phenomena and properties of a mixed atmosphere of air and vapour, it appears that clouds in general must be formed at that elevation in the atmosphere in which the mean temperature of the air becomes equal to, or falls below the point of saturation of such air. This elevation which may be said to constitute the *region of clouds*, must of course be highest under the Equator—an inference supported by fact; for it has been observed that within the tropics, the clouds are most frequently higher than in the temperate zones ; and in the temperate zones the clouds appear to be higher in summer than they are in winter. In the temperate zones Gay Lussac thinks that clouds, in general, are upheld at an average distance from the earth's surface of between 1500 and 2000 yards. Occasionally, however, clouds have a much greater altitude ; and the *Cirrus*, a form of cloud to be presently described, has been seen far above the greatest elevation hitherto attained by man.

In some parts of the world clouds are rarely seen, while in other parts the sky is seldom cloudless. Such extremes are usually confined to extreme climates, or depend upon local causes. In the temperate zones, from the irregularity of the atmospheric currents, and from the other innumerable circumstances calculated to disturb the equilibrium of the atmosphere, the general character of clouds varies much even under the same parallel of latitude. Hence all the infinite variety of sunshine, of cloud, and of shower, which more especially distinguish the temperate zones, and our

own variable sky in particular; where they exert such constant and commanding influence upon our comfort and well-being, as to become almost interwoven with our very existence.

Though clouds are of such endless diversity of *figure* and appearance, they have been classed by Howard under three primary forms, and four modifications. The three primary forms are :

The *Cirrus*, composed of fibrous-like stripes, parallel, flexuous, or diverging, and extensible in all directions.

The *Cumulus*, heaped together in convex, or in conical masses, and increasing upwards from a horizontal base.

The *Stratus*, spreading horizontally in a continuous layer, and increasing from below.

The first of these forms, the cirrus, is confined chiefly to the higher regions of the atmosphere. The second form, the cumulus occupies a lower but still an elevated station ; while the third form, the stratus, usually rests on the surface of the earth, constituting the mist already described in this chapter.

Of the four modified forms of clouds, two are intermediate, and two are composite.

The first of the intermediate forms is the *Cirro-Cumulus*, consisting of small roundish, and well-defined masses in close horizontal arrangement.

The masses that compose the second intermediate form of clouds, the *Cirro-Stratus*, are likewise small and rounded, and are attenuated towards a part or towards the whole of their circumference. They are sometimes separate ; when in groups, their arrangement is either horizontal, or slightly inclined, and the masses are either bent downwards, or are undulated.

Of the two composite forms of clouds, the first is the *Cumulo-Stratus*, made up of the Cirro-Stratus blended with the Cumulus ; the Cirro-Stratus being either intermingled with the larger masses of the Cumulus, or widely enlarging the cumulous base.

The second composite form, and the last of the four modifications, of clouds, is the *Cumulo-Cirro-Stratus*, or *Nimbus*, the *rain-cloud ;* being that cloud or system of clouds from which rain is falling. The nimbus is a horizontal layer of aqueous vapour, over which, clouds of the cirrous form are spread, while other clouds of the cumulous form enter it laterally and from beneath.

A little attention will enable any one to discriminate these varieties of clouds, at least when their forms are well defined. Yet, it must be acknowledged that clouds often assume forms to which it is difficult to give a name.

With respect to the *motion* of clouds, it may be remarked that there is not perhaps a more frequent subject of optical delusion, nor anything regarding which, we are more liable to be mistaken,

Into such inquiry it would be quite inconsistent with the design of this treatise were we to enter minutely; but we offer the following brief illustration. Let us suppose a cloud moving from the distant horizon towards the place where we stand. Let us also suppose that the cloud during its motion retains the same size and figure, and that it proceeds along its course in a uniform horizontal line. A cloud so moving, when first seen, will appear to be in contact with the distant horizon; and will thus necessarily, from its remote position appear to be much smaller than in reality it is. During its advance towards us, the cloud will seem to rise into the sky, and to become gradually larger, till it is almost directly overhead. Continuing its progress it will then seem again to descend from the zenith, and to lessen in size as gradually as it had before increased, till at last it vanishes in the distance, opposite to where it commenced its movement. Thus the same cloud, without deviating from its motion in a straight line, and retaining throughout the same size and figure, will, by optical delusion, seem continually to vary in magnitude. The line of its motion also, instead of being straight, will appear to be a curve having its vertex directly above us, and its extremes boundless in opposite points of the horizon. We have given the most simple case that can be supposed. But clouds, as they exist in nature are unceasingly varying in shape, in magnitude, in direction, and in velocity; so that to form a just estimate of their figure and direction, or to unravel their motions, becomes absolutely impossible.

After what has been stated, it will be superfluous to dwell upon the *uses* of clouds in the economy of nature; we shall therefore briefly remind the reader of a few only of the most obvious benefits derived from clouds. The first of these that claims our attention is, that upon the large scale at least, clouds constitute a sort of intermediate state of existence between vapour and water, by which sudden depositions of water and their consequences are entirely prevented. If all the water separated from the atmosphere fell at once to the earth, in the state of water, we should be constantly liable to deluges and other inconveniences, the whole of which are obviated by the present beautiful arrangement. Again clouds are one great means by which water is transported from seas and oceans to be deposited far inland, where water otherwise would never reach. Clouds also greatly mitigate the extremes of temperature. By day they shield vegetation from the scorching influence of the solar heat, and produce all the agreeable vicissitudes of shade and sunshine: by night, the earth, wrapt in its mantle of clouds, is enabled to retain that heat which would otherwise radiate into space, and is thus protected from the opposite influence of the nocturnal cold. These bene-

fits arising from clouds are most felt in countries without the Tropics, which are most liable to extremes of temperature. Indeed, clouds constitute one great means by which, in temperate climates, the extremes of heat and cold are regulated. Lastly, whether we contemplate them with respect to their form, their colour, their numerous modifications, or, more than all, their incessant state of change, clouds prove a source of never-failing interest, and may be classed among the most beautiful objects in nature.

Having finished the consideration of the various states of visible vapour, we are now to examine the phenomena of the precipitation of water from the atmosphere in the form of *Snow*, *Sleet*, *Rain*, and *Hail*. We shall first speak,

Of Snow.—We commence with snow because it offers the most simple case of the precipitation of water from the atmosphere; snow being nothing more than the frozen visible vapour composing clouds. Hence a flake of snow examined with a high magnifier exhibits a beautiful display of minute crystals, often possessing the greatest variety of form.

When the temperature of the atmosphere, down to the earth's surface, is constantly below the freezing point, it is obvious that any moisture separated from the atmosphere must assume the solid form. If the quantity separated be small, the frozen particles of water remaining detached, float in the atmosphere in the form of crystallized spiculæ, and thus give origin to what is called the *frost-smoke*, a phenomena not unfrequently witnessed in polar latitudes. Even in temperate climates, the same thing has been supposed occasionally to take place in the higher regions of the atmosphere, and thus to produce certain optical phenomena to which we shall hereafter refer.

The above are comparatively rare phenomena. Most generally the quantity of water separated is so large that the crystallized particles are agglutinated together into masses or *flakes*, and thus fall to the earth in the form of snow. When the quantity deposited is very great, as is often the case, there can be no doubt that the causes operating to produce such large deposition, are precisely similar to those which produce rain in warmer climates, and which will be considered in a subsequent paragraph.

Such, in few words, are the principles upon which snow is formed, and from these the reason is at once apparent, why during the winter in temperate climates, and throughout the whole year in the polar climates, most of the water that falls to the earth assumes the form of snow.

We formerly mentioned how much we owe to the *whiteness* of snow; and we may now remark that we owe still more to its *low conducting properties*, and to its *lightness*. Thus by its low conducting properties snow shields vegetation from the rigo-

rous cold of the higher latitudes, where every thing herbaceous would be destroyed during the winter, were it not for the protecting influence of snow. Again if the water which now descends to the earth as snow, were to be precipitated in the form of solid masses of ice, vegetation would be destroyed, and the whole of the colder parts of the earth would be uninhabitable!

It has been remarked, in temperate climates more especially, that the air is usually warmer during a fall of snow, than before or after. This increase of temperature probably arises from the extrication of heat in the sensible form during the transition of the vapour from a fluid to a solid state. Snow-water has also been said to contain much oxygen, and thus to be particularly favourable to vegetation.

Sleet is snow in a half melted condition, and constitutes the intermediate state between snow and rain, to be next considered.

Of Rain.—When the temperature of the air is above 32°, the freezing point of water, the water separated from the air falls to the earth in the state of rain. Such is a general expression of the fact; but after all the attention that has been bestowed on the phenomena of rain, many difficulties attend the investigation, that have not yet been surmounted.

It cannot be doubted that rain is in some way connected with change of temperature; the perplexity attending the subject, arises, partly from the impossibility in many instances of accounting for the supposed change of temperature; but much more from the difficulty of understanding how this change of temperature operates. According to the usual opinion, the precipitation of water from the atmosphere is the effect of the mingling together of currents of warm and of cold air, which are supposed to operate on each other in the following manner.

From the law of the tension of vapour, already described, it follows, that when two currents of air having different temperatures, but both alike saturated with vapour, are mixed together; though the resulting temperature of the mixture will be the mean of the two, the resulting tension of the vapour will not be likewise the mean. The resulting tension of the vapour will always *exceed* the tension belonging to the resulting mean temperature; consequently there will be an excess of vapour which will be precipitated in the form of water. Thus let us suppose two currents of air, both saturated with vapour, the one having a temperature of 40°, and the other a temperature of 60° and that these two currents of air are mingled together;

	Inches of Mercury.
The tension or elastic force of vapour at 40° is equal to -	.263
- - - - - - - - - of vapour at 60° is - - - -	.524

Whence it appears that the mean temperature of the two volumes of air is 50°, and the mean of the elasticities of their vapour .393 inches. But the actual tension or elastic force of vapour at 50° is not .393 inches, but only .375 inches; after the intermixture, therefore, of the two currents, a quantity of vapour will remain, proportionate to the tension of 0.18 inches; and as this superfluity of vapour cannot be held in solution by air of the mean temperature of 50°, it will be separated in the form of clouds, or of rain, according to circumstances.

Such, in few words, are the opinions respecting rain first advanced by Dr. Hutton; and notwithstanding some difficulties about these opinions, there can be little doubt of their general accuracy. The subject of condensation, in general, may perhaps receive some additional elucidation from the principles regulating a mixed atmosphere of vapour and air formerly described; and which may be thus applied. When two currents of atmospheric air of different temperatures, and each charged with vapour up to the point of saturation, are brought into contact; they will begin to intermingle in virtue of the proper motions of the air and vapour, and the immediate result will be the formation of *visible vapour*, that is to say, of a *cloud*. If the currents are continuous and uniform, the clouds soon spread in all directions, so as to occupy the whole horizon; while the additional moisture incessantly brought by the warmer current, or the occasional diffusion of vapour from a distant and colder region, keeps up a constant supply for condensation, and produces a great and continued deposition of moisture in the form of rain. By degrees the currents completely intermingle, and acquire a uniform temperature; condensation then ceases, the clouds are redissolved, and the whole face of nature, after being cooled and refreshed by the necessary rain, is again enlivened by the sunshine, thus rendered still more agreeable by its contrast with the previous gloom.

In this manner the principles formerly detailed may be applied to the explanation of the phenomena of rain; and as far as the explanation goes it is perhaps quite satisfactory. It must, however, be allowed, as we have before stated, that the utmost information which we can at present bring to bear upon the subject of the general condensation of moisture from the atmosphere, and of rain in particular, leaves it involved in considerable obscurity.

The following additional particulars regarding the *effects of different localities*, and of *different circumstances in the same locality* which appear to influence the fall of rain, may interest the general reader.

It has been remarked that in the greater number of instances more rain falls in the neighbourhood of the *sea* than in the sea; a fact easily understood from the principles that have been stated.

Among *mountains* also more rain falls than on plains; the excess is indeed striking. Thus in our own country, at Kendal and at Keswick, both inclosed by mountains, the annual fall of rain amounts to 67½ and 54 inches respectively, while in many inland places the quantity of rain that falls in the course of a year hardly exceeds 25 inches. So at Paris, the annual fall of rain is only about 20 inches, but at Geneva 42½ inches; and on the Great St. Bernard, the highest meteorological station in Europe, upwards of 63 inches of rain fall during the twelve months.

Although more rain falls in mountainous districts than in plains, it has been completely established, that more rain falls at the foot of a mountain, than on its top. In general, too, a larger proportion of rain is separated from the air, near the *earth's surface*, than at any height above it; a discrepancy of which the present extent of our knowledge does not enable us to give a satisfactory explanation.

In most *Tropical countries* rain falls only at particular seasons of the year, there being scarcely any rain during the other seasons. Thus, at Bombay, the rainy months are June, July, August, September, and October, while the other months are almost without rain; but on the opposite side of India, along the Coromandel coast, the time of the occurrence of the rainy season is reversed; a fact strikingly illustrative of the effect of the intervention of the high table land that separates the two coasts, and which probably, by influencing the atmospheric currents, give rise to this singular alternation of weather.

In *temperate climates*, though the total quantity of rain that falls be much less than within the Tropics, there is no protracted dry season; and the rainy days in the year are more numerous the nearer we go to the Poles. Still in general, more rain seems to fall in temperate climates during the last six, than during the first six months of the year.

Among the circumstances which influence the quantity of rain in the same locality, the most remarkable are *diminution of temperature*, and the *unusual prevalence of certain winds*.

With respect to *diminution of temperature* it has been observed that almost all wet seasons, or at least wet summers, in temperate climates, are unusually *cold*. Now from the principles formerly advanced it will be easily understood, how a depression of the temperature below the general standard in any locality, may give rise to a greater precipitation of moisture in that locality. The locality that has become colder than those around it, acts as a refrigeratory, and not only condenses and thus deprives of their elastic force, all the vapours that are in contact with it; but the neighbouring vapours rush towards the colder locality as towards a vacuum, either in the form of visible vapour or clouds, in

which case they are carried by the winds ; or as invisible vapour, in which form their movement may be determined by diffusion.

The effect of the *unusual prevalence* of certain winds in producing an increase of rain, or the reverse, is well known, and is quite intelligible on the principles we have explained. Thus in tropical climates, during the steady prevalence of the trade winds, the currents intermingle but little, the atmosphere is perfectly cloudless, and no condensation takes place. But when these great currents, following the course of the sun, begin at certain seasons of the year to shift their direction ; their uniform course suffers derangement, they become intermixed, and condensations of moisture commensurate with the high temperature, are produced to an extent quite unknown in temperate climates. These condensations form the violent periodical rains of hot climates. So also in temperate climates, as for instance in our own country, winds coming from the south and from the west, are from a warmer climate, and hold much vapour in solution ; while winds from the opposite points are colder, and therefore relatively drier. Hence winds from the south and from the west, are more frequently accompanied by rain, than winds from the north and from the east : though as we might expect, the precipitation of rain is most decided during the conflicts between these opposite currents, which sometimes extend over a large tract of country. The long prevalence of certain winds may thus cause the seasons to be wet in one part of the world, and dry in another ; the water being as it were, distilled off from the one, in order that it may be precipitated on the other. Yet the whole amount of the rain in the two countries may perhaps differ very little from the usual average, while the two countries have the benefit of variety in the general amount of their rain ; which variety may be salutary at particular periods, and may even be necessary to their well-being.

Before we end the examination of the phenomena of rain, it may be proper to advert to the generally admitted influence of the *Moon* on the weather, and especially on the fall of rain. This influence, however, can hardly in the present state of our knowledge be brought to elucidate the phenomena of rain ; so great are the disturbing effects of local and other peculiarities.

Of Hail.—The last form in which we have to consider the precipitation of water from the atmosphere, is hail. Hail may be regarded as consisting of drops of rain more or less suddenly frozen by exposure to a temperature below 32°. If the degree of cold has been very sudden and intense, which is often the case, the icy nucleus, from its being of a temperature far below the freezing point, acquires magnitude as it descends, by condensing on its surface the vapour of the lower regions of the atmosphere. Hence, even under ordinary circumstances, hail stones often become of

considerable size, are nearly always more or less rounded, and when broken are seen to be composed of concentric layers.

From what has been stated it will be readily inferred that hail is not a product of extreme climates; indeed hail may be said to be peculiar to temperate climates, as it rarely ever occurs beyond the latitude of 60°. Hail is most frequent in spring and in summer, when it is often accompanied by thunder. It seldom hails in winter, and hail during the night is very uncommon. In tropical countries there is little hail in any place that is not more than 2000 feet above the level of the sea: in temperate climates, on the contrary, mountain tops are almost free from hail. Certain countries, especially some parts of France, are very liable to hail storms; and such is at times the fury of these storms that they lay waste whole districts. There are on record many instances of these calamitous visitations, which are usually accompanied by whirlwinds and by the most appalling electrical phenomena. During storms of such degree of severity, hail stones have sometimes fallen of enormous magnitude, and often of an irregular shape, as if they were the fragments of a thick sheet of ice suddenly broken: a supposition which alone will explain the formation of angular masses, many inches in size, and many pounds in weight. The production in the middle of summer of the intense cold that is thus indicated is a puzzle which philosophers have been unable to solve.

Of the Distribution of Heat and Light in their latent and decomposed Forms through the Vapour of the Atmosphere; and of the Effects of that Distribution.—The general distribution of heat and light in their latent forms through the vapour of the atmosphere, seems to follow the same laws as the distribution of sensible heat formerly explained. That is to say, the distribution of these forms of heat and light decreases from the Equator toward the Poles. The most remarkable effects of the distribution of latent heat have already been incidentally mentioned, and need not be here repeated. We shall therefore proceed to consider the particular distribution of the decomposed forms of heat and light in the vapour of the atmosphere, and the effects of this distribution.

Of the Relations of Electricity to the Vapour of the Atmosphere.—Atmospheric air, when perfectly dry and pure, is one of the most complete non-conductors of electricity that are known. Whether water in the state of vapour possesses similar non-conducting properties does not appear to be satisfactorily established. But the non-conducting powers of aqueous vapour must be very considerable, otherwise, since the atmosphere is never entirely free from vapour, electrical insulation could not take place. On the other hand, the moment that vapour assumes the form of water, it acquires the property of being a conductor of electricity. Hence

a mass of visible vapour or cloud, when floating in a mixed atmosphere of air and vapour, is perfectly insulated, and is thus capable of electrical accumulation. Now the phenomena arising from the equalization of such derangements of electrical distribution, are *lightning* and *thunder*. Lightning and thunder therefore are nothing, either more or less, than the phenomena of electricity on a large scale; that is to say, a cloud and the earth, or two clouds, become surcharged with the two opposite forms of electricity, and thus represent the interior and the exterior coatings of an electrical jar similarly surcharged; the intervening and non-conducting air are represented by the interposed and non-conducting glass; while the lightning and the thunder are the spark and the explosion caused by the union of the two electricities. If the reader bear in mind this analogy, it will enable him to understand the whole electrical phenomena of the atmosphere.

The distribution of electricity, like that of heat and light, decreases from the Equator toward the Poles. Thus, in intertropical countries alone, are the effects of this energetic agent displayed in all their power; there, thunder storms are quite terrific, and far surpass anything of which those, who have not witnessed them, can form a conception. In temperate climates the effects of atmospheric electricity are usually most severe in the summer; and their severity is greater in mountainous districts than in plains. Yet, even under these circumstances, they are much subdued, as compared with what takes place between the Tropics; while in the Polar regions electrical phenomena are still less striking.

Notwithstanding, however, that the general distribution of electricity in the atmosphere, evidently follows the general distribution of sensible heat, it is a remarkable fact, that whenever electrical phenomena are more than ordinarily vehement, they are accompanied by some unusual appearance of *cold*. Thus the alarming descents of hail formerly noticed, which occur most generally in temperate climates, have, in nearly every instance, been attendants of violent thunder storms. Snow also is almost always highly electric. These, and many other circumstances connected with the great and sudden production of cold in the higher regions of the atmosphere, during the display of electrical agency, cannot, in the present state of our knowledge, be explained. For example, whence, in the middle of summer, arises that instantaneous developement of extreme cold, which occasionally produces the terrific hail storms above alluded to? At present the answer does not appear. Whether the principles advanced in the present volume be capable of solving the difficulty, time must determine.

With respect to the *sources* of the electricity of the atmosphere there have been many opinions. It seems now to be admitted that electrical excitement does not arise from the mere evapora-

tion and condensation of water; but that in order to produce such excitement, there must always be some chemical combination or separation.* Thus electrical excitement is the result of the chemical changes which often accompany the evaporation of water. During combustion also there is an ample evolution of electricity; the burning body giving out negative, the oxygen positive electricity. In like manner, the carbonic acid sent forth during vegetation is charged with negative electricity, and at the same time the oxygen, as is most likely, is charged with positive electricity. Derivation from these sources has been deemed quite sufficient to explain the very large quantities of electricity that are so often accumulated in the clouds. It is however probable that there are yet other causes, or at least *one* other cause, on which, in numerous instances, this accumulation may still more immediately depend. We allude to the combination of oxygen with the vapour of the atmosphere formerly mentioned. For reasons which we cannot here detail, our opinion is, that this combination of aqueous vapour with oxygen, more than any other cause whatever, is in some way concerned with the phenomena of atmospheric electricity.

The *Aurora borealis* is a phenomenon supposed to have some connection with electricity, though its precise nature is involved in considerable obscurity. The phenomenon evidently indicates currents of some kind; and if the light be electrical, we can only suppose such electrical currents to take place in an imperfectly conducting medium. That is to say, if the phenomenon, as some contend, exist in the lower regions of the atmosphere, luminous electrical currents can be produced only by water in the liquid state; if the phenomenon exist in the higher regions of the atmosphere, as at present is supposed, such currents may depend upon the extreme tenuity of the atmosphere in these higher regions. Our own opinion is, that at different times, the *aurora borealis* exists at different heights in the atmosphere, and consequently may depend upon both these causes. Has the diffusion of vapour from the Polar towards the Equatorial regions of the globe any connexion with the phenomenon?

The phenomenon depending upon the decomposition, refraction, and reflection of light by the vapour of the atmosphere are not less striking and important than those produced by electricity. To such effects upon light by the atmospheric vapour we owe not only the cærulean tint of the sky, and all the splendid colouring of the clouds, but the beneficial morning and evening twilight, nay even the light of day itself. "Were it not,"

* Pouillet, Elémens de Physique expérimentale et de Météorologie, tom. ii. p. 823.

says Sir J. Herschel, "for the reflecting and scattering power of the atmosphere, no objects would be visible to us out of direct sunshine, every shadow of a passing cloud would be pitchy darkness; the stars would be visible all day, and every apartment into which the sun had not direct admission would be involved in nocturnal obscurity." Again to use the words of the same author, in speaking of twilight,—"After the sun and moon are set, the influence of the atmosphere still continues to send us a portion of their light; not indeed by direct transmission, but by reflection upon the vapours and minute solid particles which float in it, and perhaps the actual material atoms of the air itself."* Such are the beautiful phenomena and the important results of the action of the vapour of the atmosphere upon light. It remains to mention a few others, of a similar character, produced by the same causes, but of less frequent occurrence and of less importance in the economy of nature.

The first of these minor phenomena which we shall notice is the *Mirage*, a phenomenon depending partly on the vapour of the atmosphere, and partly on the intermixture of strata of air of different temperatures and densities. The mirage is not unfrequent in level countries, when their surface is strongly heated by the sun's rays, and evaporation results from the continuance of the heat. The mirage assumes the appearance of a sheet of water, often exhibiting the reflected or inverted images of distant objects. In Egypt and in the neighbouring sandy plains, where the mirage is very common, the illusion is at times so perfect, that travellers can hardly be convinced of the non-existence of what they imagine they see.† The phenomena are quite explicable on well known optical principles.‡

Nearly allied to the mirage is the appearance termed *Fata Morgana*, which is occasionally witnessed in the Straits of Messina. There are many similar phenomena, all of them owing to the refraction of light by media of various densities.

The next class of phenomena to be noticed are those produced upon light by crystals of ice floating in the atmosphere, or by visible vapour. The angular forms of the crystals of ice, by determining the rays of light in different directions, give origin to various eccentric *halos;* which, by their united intensities, particularly where they cross one another, occasionally produce conspicuous masses of light, denominated *parhelia* and *paraselenes*, or *mock suns* and *mock moons*. Visible vapours, consisting of water in the fluid state, likewise sometimes form *halos;* but

* Treatise on Astronomy, p. 33.

† See Clarke's Travels.

‡ See Wollaston, Philosophical Transactions, 1800, p. 239.

these halos (when more than one exists) are always concentric, the sun or moon being in the centre. These two phenomena not unfrequently take place at the same time.

The last and most frequent phenomenon of the general kind which we shall notice is produced by the action of *fluid drops* of water upon light, viz. the well known phenomenon termed the *Rainbow*. The concomitants of the rainbow are familiar to every one: there must be rain along with sunshine. Under these circumstances if the spectator turns his back to the sun, he sees the coloured bow project on the opposite cloud, and displaying all the tints of the prismatic spectrum.

We are informed in the sacred narrative, that this beautiful phenomenon was chosen as a symbol to mankind of their exemption from future deluge. The sceptic may be challenged to state what pledge could have been more felicitous or more satisfactory. In order that the rainbow may appear, the clouds must be *partial*. Hence the existence of the rainbow is absolutely incompatible with *universal* deluge from above. So long, therefore, as "He doth set his bow in the clouds" so long have we full assurance that these clouds must continue to shower down good and not evil upon the earth.

3. *Of the Occasional Presence of Foreign Bodies in the atmosphere and of their Effects.*—The foreign bodies that occasionally exist in the atmosphere may be considered as of two kinds; viz. *those which are merely suspended in the atmosphere in a state of mixture;* and *those which pervade the atmosphere in a state of solution.*

Both in ancient and in modern times, and in various parts of the world, rain and snow have been observed to be coloured by an admixture of extraneous matters. The nature of these colouring matters has been found to be very different in different instances; some have proved to be of vegetable origin, consisting of *minute lichens* and *other cryptogamous plants*, brought from a distance by the agency of the winds, and diffused in myriads through the atmosphere. Such vegetable matters have been sometimes more or less *red:* whence those imagined *showers of blood* we read of as producing so much popular excitation. In other instances the colour has been given by earthy and metallic matters in a state of very fine powder, and in this case their descent has been usually accompanied by violent electrical phenomena, similar to those which almost always attend the descent of *Meteoric stones* or *Aerolites*, to which perhaps they are nearly allied.

Of the falling of stones from the atmosphere, there can now be no doubt; though the origin and the nature of these stones are very obscure, and indeed cannot, in the present state of our knowledge, be explained. There have been various opinions on

the subject. Some, considering aerolites to be the productions of our own planet, have viewed them as masses projected from volcanoes to a great height and distance in the atmosphere; or as formed by the agglutination of the earthy and metallic powders from volcanoes, as before mentioned. Others ascribing to aerolites quite a different origin, have viewed them as fragments scattered through space, which happening to come within the sphere of our earth's attraction, have been determined to its surface, &c.

Although we are thus uncertain regarding the origin of aerolites, or their use in the economy of nature; it now seems by innumerable observations to be completely established, that aerolites, while in the higher regions of the atmosphere, are often in a state of intense ignition. They there assume the form of brilliant meteors, which as they approach the earth, burst with a loud explosion, followed by a shower of stones. These stones generally exhibit evident marks of fusion: and many of them have been picked up while still warm, so as to leave no doubt of their being real aerolites. It is singular too, that the composition of aerolites is in some degree peculiar. They invariably contain, either iron, or cobalt, or nickel, or all these three metals, in union with various earthy substances. Aerolites have been found of every size, from that of a few grains to the weight of several hundreds of pounds; for of this weight are some of those isolated masses of iron seen in different parts of the world, and which are generally allowed to be of meteoric origin.

Intermediate, as it were, between substances suspended, and substances dissolved, in the atmosphere, are those matters, whatever their nature may be, which have been known to spread as a haze over large districts, and have been termed "*Dry Fogs.*"

In the year 1782, and still more in the year following, a remarkable haze of this kind extended over the whole of Europe. Seen in mass this haze was of a pale blue colour. It was thickest at noon, when the sun appeared through it of a red colour. Rain did not in the least degree affect it. This haze is said to have possessed drying properties, and to have occasionally yielded a strong and peculiar odour. It is also said to have deposited in some places a viscid liquid, of an acrid taste, and of an unpleasant smell. About the same time, there were, in Calabria and in Iceland, terrible earthquakes, accompanied by volcanic eruptions. These earthquakes and eruptions were supposed to have been connected with the haze. Indeed it has been generally remarked, that such a condition of the atmosphere has been usually preceded by an earthquake, either in the same or in some adjoining country. The dispersion of this haze in the summer of 1783 was attended by severe thunder storms. As might be expected, the general state of health has, for the most part, been deranged

during the continuance of these phenomena. Simultaneously there have been epidemic diseases of various kinds. Thus, in the above mentioned years, 1782 and 1783, an epidemic catarrh, or influenza, prevailed throughout Europe; affecting not only mankind but likewise other animals.*

The nature of the matter thus diffused through the atmosphere is quite unknown. It may be as various at different times as the character of the epidemics to which it gives origin. As an example of the extraordinary effects which foreign bodies, when diffused through the atmosphere, are capable of producing, we may mention those produced by Selenium when, in combination with hydrogen, it is diffused as a gas through the air, even in the most minute quantity. The effects of this gaseous combination of selenium with hydrogen are thus described by the celebrated chemist, Berzelius, its discoverer. "In the first experiment which I made on the inhalation of this gas, I conceive that I let up into my nostrils a bubble of gas, about the size of a small pea. It deprived me so completely of the sense of smell, that I could apply a bottle of concentrated ammonia to my nose without perceiving any odour. After five or six hours, I began to recover the sense of smell, but a severe catarrh remained for about fifteen days. On another occasion, while preparing this gas, I became sensible of a slight hepatic odour, because the vessel was not quite close; but the aperture was very small, and when I covered it with a drop of water, small bubbles were seen to issue, about the size of a pin's head. To avoid being incommoded with the gas, I put the apparatus under the chimney of the laboratory. I felt at first a sharp sensation in my nose; my eyes then became red, and other symptoms of catarrh began to appear, but only to a trifling extent. In half an hour I was seized with a dry and painful cough, which continued for a long time, and which was at last accompanied by an expectoration, having a taste entirely like that of the vapour from a boiling solution of corrosive sublimate. These symptoms were removed by the application of a blister to my chest. *The quantity* of Seleniuretted Hydrogen Gas which on each of these occasions entered into my organs of respiration *was much smaller* than would have been required of any other inorganic substance whatever, to produce similar effects.'†

As we have already stated, selenium is for the most part found in association with mineral sulphur. Selenium is also, like sulphur, a volcanic product. Now, though we can hardly imagine the possibility of the diffusion of selenium through the atmo-

* See article Influenza, in the Encyclopædia of Practical Medicine.

† Annals of Philosophy, Old Series, vol. xiv. p. 101.

sphere in combination with hydrogen ; selenium may be so diffused in some other form of combination, which may produce effects analagous to those of seleniuretted hydrogen. We do not mean to assert that the diffusion of any such substance really takes place. Our intention is merely to show that a small quantity of an active ingredient, like selenium, is sufficient to contaminate the atmosphere over a wide extent of country. Such a substance being ejected from the crater of a volcano during an eruption, or through a crevice in the earth during an earthquake, may thus produce an epidemic disease. Nor is it improbable that many epidemics, particularly those of a catarrhal kind, have so originated.

The matters occasionally diffused through the atmosphere, which appear to be *in a state of solution*, are not often perceptible by our senses, unless in some cases, perhaps, by the sense of smell.

As an instance of the presence of such bodies in the atmosphere we may mention a very remarkable observation which occurred to the writer of this treatise during the late prevalence of epidemic cholera. He had for some years been occupied in investigations regarding the atmosphere ; and for more than six weeks previously to the appearance of cholera in London, had almost every day been engaged in endeavouring to determine, with the utmost possible accuracy, the weight of a given quantity of air, under precisely the same circumstances of temperature and of pressure. On a particular day, the 9th of February, 1832, the weight of the air suddenly appeared to rise above the usual standard. As the rise was at the time supposed to be the result of some accidental error, or of some derangement in the apparatus employed ; in order to discover its cause, the succeeding observations were made with the most rigid scrutiny. But no error or derangement whatever could be detected. On the days immediately following, the weight of the air still continued above the standard ; though not quite so high as on the 9th of February, when the change was first noticed. The air retained its augmented weight during the whole time these experiments were carried on, namely, about six weeks longer. The increase of the weight of the air observed in these experiments was small ; but still decided, and real. The method of conducting the experiments was such as not to allow of an error, at least to an amount so great as the additional weight, without the cause of that error having become apparent. There seems, therefore, to be only one mode of rationally explaining this increased weight of the air at London in February, 1832 ; which is, by admitting the diffusion of some gaseous body through the air of this city, considerably heavier than the air it displaced. About the 9th of February the

wind in London, which had previously been west, veered round to the east, and remained pretty steadily in that quarter till the end of the month. Now, precisely on the change of the wind the first cases of epidemic cholera were reported in London; and from that time the disease continued to spread. That the epidemic cholera was the effect of the peculiar condition of the atmosphere, is more perhaps than can be safely maintained; but reasons, which have been advanced elsewhere, lead the writer of this treatise to believe that the virulent disease, termed cholera, was owing to the same matter that produced the additional weight of the air. The statement of these reasons here would be quite out of place: it is enough to say, that they are principally founded on remarkable changes in certain secretions of the human body, which, during the prevalence of the epidemic, were observed to be almost universal; and that analogous changes have been observed in the same secretions of those, who have been much exposed to what has been termed *Malaria*. The foreign body, therefore, that was diffused through the atmosphere of London, in February, 1832, was probably a variety of malaria, a subject which we now proceed to consider.

In districts partially covered with water, and having a luxuriant vegetation, such as marshes and fens, particularly in warm countries: or in colder countries, at seasons of the year when the sun is most powerful; noxious exhalations arise, whose nature differs perhaps in some degree according to the locality. Such exhalations have received the general name of Malaria, and are well known to be the fertile source of various diseases, more or less, of the intermittent febrile type. In cold and in temperate climates, these diseases for the most part assume the character of regular ague, or of rheumatism: but on approaching to, and within the Tropics, they appear as the more formidable remittent and continued fevers, the well-known scourges of hot climates.

With respect to the nature of these exhalations our knowledge is very imperfect. Evidently, they are in some way connected with vegetation; not however with vegetation living and in a state of growth, but with vegetation in a state of decay. It has therefore been thought likely that these exhalations contain some gaseous body, composed chiefly of hydrogen and carbon. Their effect may arise from a gaseous compound of this description, though no such compound is at present known; and the probability is, that malaria occasionally owes its properties to other elements, besides the hydrogen and carbon disengaged from decaying vegetables.

We have thus endeavoured to give a concise statement of that wonderful assemblage of Laws, of Adaptations, and of Arrangements, which viewed together constitute what we term *Climate*; and which, as affecting the welfare of the denizens of this globe,

undoubtedly, are not surpassed in interest or importance by any others throughout the whole of nature. Of the innumerable suns and planets that may occupy the boundless expanse of the universe we feel not the influence; even their existence scarcely obtrudes itself upon our notice. But in the light and the heat of our own sun, and in the wind and the rain of our own atmosphere, every organized being on this earth, from Man, the Lord of its creation, down to the humblest plant that drinks the dew, is alike most intimately concerned. The subject of Meteorology, therefore, in all ages and countries, has attracted the especial attention of mankind. In ruder states of society empirical prognostics, founded on the aspects of the clouds, on the movements of animals, and on other incidental occurrences, formed the study of those who pretended to a foreknowledge of the weather; while electrical phenomena were to them objects of superstitious awe. In modern times much of this wonder and uncertainty has been removed. The gloom or the clearness of the air, the mists and the halos of a stormy sky, the restlessness and clamour of animals, &c., are now referred simply to that overcharge of moisture, and to that unequal distribution of electricity which precede a fall of rain. Nay, the very thunderbolt has been arrested in its course, and from being no longer an object of amazement, has been divested of half its terrors.

But is this advance in knowledge calculated to lessen our veneration for the great Author of nature, or to derogate from his wisdom and his power? On the contrary, our estimate of both must be greatly increased. Of the Deity, infinite as he is, and dwelling in infinity, we finite beings can form no conception. What little, therefore, we can know of Him, we know nearly altogether from His works. Consequently he who has the most studied His works, will be the best qualified—nay, will be alone qualified, to form an adequate conception of Him. Thus to measure, to weigh, to estimate, to deduce, may be considered as the noblest privileges enjoyed by man; for only by these operations is he enabled to follow the footsteps of his Maker and to trace His great designs. Instructed by these, he sees and appreciates the wisdom and the power, the justice and the benevolence that reign throughout creation: he no longer gazes on the sky with stupid wonder; nor dreads the thunderbolt as manifesting the wrath of a vengeful Deity.

The constituents of climate, even imperfectly as they can be understood by us, are seen to be adjusted and arranged in a manner so surprising, that to those who admit the existence of design, they require only to be stated and apprehended, in order to their being received as additional proofs of that great argument. Where all are great, and splendid, and good, selection is precluded; but

the circumstances accompanying the distribution of Water over this globe, more perhaps than any other, arrest our notice as indicative of design. Leaving out of view the other properties of water; on what other supposition, besides that of design, can we account for all these astonishing properties on which depend its evaporation and diffusion through the atmosphere—its subsequent condensation, not at once in the form of water or of ice, but in the intermediate state of clouds—its colour and lightness when in the state of snow—its power of refracting light and of conducting electricity—in short, all the numerous, minute, and happily contrived qualities displayed by this highly elaborated fluid? These together form such a union of adaptations and arrangements, each most successfully accomplishing a particular purpose, and apparently directed to, and designed for, that purpose, that to doubt the agency of design would seem impossible. Yet there are some men's minds so warped that they either cannot or will not be persuaded of the existence of design; but asserting the omnipotence of the laws of nature, they forget Him who framed these laws, and are reluctant to give credence to His being or to His power. To such persons Meteorology offers one or two exclusive arguments, which, at the risk of being accused of tediousness, and unnecessary repetition, we shall urge briefly in this place.

The great Author of Nature, as we have before said, has chosen to act agreeably to certain established laws, by which he is invariably guided. Some of these laws we are able more or less to comprehend, and we can refer them to more general principles. Others are beyond our comprehension: we see only their effects; and even these effects are most imperfectly revealed to us. As instances of the laws of nature which it is in our power to refer to general principles, may be mentioned the currents in the ocean and in the atmosphere, by which the equilibrium of temperature over the globe is maintained. These currents, we know, are strictly referrible to hydrostatic and pneumatic principles. The argument of design, which is deducible from these principles, rests, therefore, not so much on the principles themselves, as on their application precisely where they are requisite. On the other hand, as we stated at the commencement of this book, the laws of chemistry are founded solely on experience; so that our acquaintance with them is very defective; for in very few instances are they referrible to the laws of quantity, and even when they can be so referred, it is only in a manner very imperfect. But though we do not comprehend the laws of chemistry, we see that many of them, perhaps all, in so far as they are intelligible to us, are entirely consistent with each other; and are as uniform in their operation as those which obviously depend on mechanical

principles, or on the laws of gravity. Thus the laws, that all bodies are expanded by heat and are contracted by cold—that chemical substances do not mix, but always combine in certain proportions, and in no others,—are general laws, to which there are so few exceptions, that they are calculated on almost with as much certainty, in the operations of nature, and in the common intercourse of mankind; as the invariable and necessary results, that a heavy body will fall to the earth, or that two and two make four. We have selected these laws of chemistry partly from their general and indisputable character, and partly that the force of the argument which follows may be more conspicuous:

All bodies are expanded by heat and contracted by cold. If water had not constituted an exception to this law, though all its other properties had been the same as they now are, long before this time, as we have seen, half the water on the globe would have been converted into ice; and the existence of organized beings would have been physically impossible.

All chemical substances combine in certain proportions, and in no others. If air had been formed according to this law, everything else being the same as at present, long before this time, half of the air in the atmosphere would have been contaminated and rendered unfit for the support of animal life. In order, therefore, that *water might not be frozen;* and that *air might not become irrespirable; laws must be infringed*—and THEY ARE INFRINGED; infringed too, precisely where their infringement, both in kind and degree, is indispensably necessary to organic existence. Now, we appeal to the most inflexible sceptic regarding the argument of design, and ask him, on what other principle, unless that of express adaptation and design, can two such general laws have been infringed exactly in those instances in which their infringement is wanted, and nowhere else? Of the sophistry by which the evasion of this plain question may be attempted, we are quite ignorant. But we cannot resist the conviction, that one purpose of the arrangement has been that of confounding the presumptuous sceptic; who is thus perpetually reminded of the infringement of his boasted "laws of nature," by the very water he drinks, and by the very air he breathes.

With respect to foreign bodies in the atmosphere, which have been treated of in the last section, it remains to observe, that though of very opposite characters, they have yet this resemblance; that they all apparently exist less on their own account, than as being the inevitable results of general laws established for a higher purpose. Such results of general laws may be considered as analogous to the coldness and darkness, which necessarily prevail around the poles, from the earth's position in relation to the sun; and they have been alike permitted, not because

they could not have been avoided or removed, but in the language of Paley, before quoted, "because the Deity has been pleased to prescribe limits to his own power, and to work his ends within these limits."

Man, forgetting how insignificant he is, and how limited his utmost knowledge, is too apt to measure Omnipotence by the standard of his own narrow intellect, and to be guided by his own selfish feelings, in judging of the extent of Divine benevolence. That this earth, a minute fraction, as it is, of a great and wonderful system, should be amenable to the general laws by which the whole system is governed, is, at the least, exceedingly probable. Of such general laws, of their changes, of their aberrations, or of their influences, we, situated in this extremity of the universe, cannot see the object. What, therefore, appears to us anomalous or defective, may in reality be parts of some great cycle or series, too vast to be comprehended by the human mind, and only known to beings of a higher order, or to the Creator himself. So again, amidst the desolation of the hurricane, or of the thunder storm; in the settled affliction of malaria, and in the march of the pestilence; the goodness of the Deity is impugned, his power even, is regarded doubtfully. But what, in truth, are all these visitations but so many examples of the "unsearchable ways" of the Almighty; "He sits on the whirlwind, and directs the storm:" a hamlet is laid waste; a few individuals may perish; but the general result is good: the atmosphere is purified; and pestilence with all its train of evils disappear. Nay, however inscrutable the object of the deadly malaria itself, do we not see one end which it serves, namely, to stimulate the reasoning powers, and the industry of man? By his reason, man has been guided to an antidote beneficently adapted for his use, which has stript malaria of half its terrors. By his industry, the marsh has been converted into fertile land, and disease has given place to salubrity.

When, therefore, we duly consider all these things; when we reflect also on the number, the properties, the various conditions of the matters composing our globe; the wonder surely is, not that a few of these matters occasionally exist as foreign bodies in the atmosphere, but that others of these matters are not at all times diffused through it, and in such quantity as to be incompatible with organic life. Thus, the original constitution of the atmosphere, and the preservation of its purity against all these contaminating influences, may be viewed as the strongest arguments we possess, in demonstration of the benevolence, the wisdom, and the omnipotence of the Deity: benevolence in having willed such a positive good; wisdom in having contrived it; and omnipotence in having created it, and in still upholding its existence.

CHAPTER VI.

OF THE ADAPTATION OF ORGANIZED BEINGS TO CLIMATE; COMPREHENDING A GENERAL SKETCH OF THE DISTRIBUTION OF PLANTS AND ANIMALS OVER THE GLOBE; AND OF THE PRESENT POSITION AND FUTURE PROSPECTS OF MAN.

In the general survey of climate, and of its reference to organization, given in the preceding chapter, we have seen, on the one hand, that, by a series of wonderful expedients, the climate or temperature of the greater portion of the earth's surface has been so equalized as to be brought within the range of organic existence. On the other hand, we shall find that, by a series of expedients, no less wonderful, organic existence has been so diversified and extended, as to include all the possible varieties of soil and climate. Hence, the arrangement, taken altogether, presents us with such extraordinary instances of mutual adaptation of its various constituents to each other, as to admit of explanation only upon the supposition of the whole being different parts of the same magnificent Design; while the infinite variety, where all might have been otherwise, must be considered as equally indicative of the Benevolence,and the Power of the Designer.

Next to Climate, the circumstances in which organized beings are more immediately concerned is Soil; a subject already alluded to, but which it will be necessary to illustrate a little further before we proceed.

The soil is that collection of matters, more or less in a state of comminution, which immediately covering the general surface of the earth, fills up its minor inequalities, and rounds off its asperities. On this layer of comminuted mineral substances and organic remains, all vegetables and animals, at least all land animals, depend for their existence; and, if there ever was a time when the materials composing this globe were collected into solid masses, it is evident that such a condition must have excluded organic life; even if everything else had existed the same as at present.

The formation of the soil has apparently been a work of time, and the result of the gradual attrition of the solid materials composing the crust of this globe. Hence the formation of soil has probably been always progressive, and is still going on. Besides this gradual attrition, the harder materials of our globe seem to have suffered much disintegration during those periodic convulsions formerly mentioned. By the same convulsions, also, the different comminuted materials have evidently been mixed and

scattered, and finally deposited over the surface of the whole earth, so as to give occasion to that infinite variety which everywhere prevails.

The foregoing remarks naturally lead to the conclusion that the characters of the soil will generally agree with those of the rocks composing the crust of the earth; and this inference is correct. The more common ingredients in rocks are silex, alumina, lime, magnesia, and iron; and these mineral matters actually constitute the greater bulk of every soil. The remaining matters consist of more or less of various other earthy and saline principles, and of vegetable and animal remains.

After these general observations upon soils, we come to the proper subject of this chapter, which we shall consider under the three following sections:—*Of the Distribution of Plants over the globe;—Of the Distribution of Animals over the globe;* and,—*Of the present Condition and future Prospects of Man.*

Section I.

Of the Distribution of Plants over the Globe.

From what has been stated, it will be readily understood that Soil and Climate are the two great and immediate causes by which vegetable and animal existence are likely to be affected. We shall, therefore, in the first place, take a view,

1. *Of the differences of Vegetation, as liable to be influenced by Soil, and by other minor Local Circumstances, in the same Climate.* The most incurious observer, in travelling through a country, must be struck with the different vegetation that prevails in different parts of the country; and with the effect which this difference produces on the manners and on the health of the inhabitants. Thus, in some parts of England, the *Apple* and the *Pear* are seen growing spontaneously in every hedge-row; while, in other parts, apple and pear trees will not flourish, even with the utmost care. Some situations are favourable to the *Oak*, others to the *Beech*, others to the *Elm*. Accordingly, these well-known and beautiful trees predominate in some districts, almost to the exclusion of every other, and thus constitute the leading feature in the landscape.

These are familiar examples of partial changes among the larger vegetables of a country; while the general vegetation is supposed to remain nearly the same. Between such partial change, and the complete establishment of a peculiar vegetation, there exists among different localities, every possible shade of diversity. Many of these differences in vegetation are obviously connected with

differences in soil and in situation. Thus, some plants will thrive only on a calcareous soil; as a few of the *Orchis* tribe in our own country, and the *Teucrium montanum* in Switzerland. Others, like the *Salsolas* and the *Salicornias*, will only grow in salt marshes. Some plants flourish in sea water, some in fresh; while to others again, water, at least in excess, is so prejudicial, that they can exist nowhere, unless on bare rocks, or in arid deserts. Mountainous situations are most favourable to the increase of some plants, while others abound in plains. The larger number of plants prefer sunshine, but some are most vigorous in the shade; and others are so impatient of light, that they are found only where there is absolute darkness. There are, besides, parasitic plants, like the *Mistletoe*, whose nourishment is derived from the plants to which they are attached. In short, the varieties in the nature of plants are countless, nor is the enumeration of them requisite. What has been stated is more than enough to show the wonderful arrangements that have been made, to ensure the clothing of every part of the earth's surface with vegetable organization. There is not a soil, however barren, nor a rock, however flinty, that has not its appropriate plant; which plant has no less wonderfully found its way to the spot adapted for it, nay, will perish if removed elsewhere. Saline plants, for instance, will grow only where saline matters are abundant; plants of the marsh, and of the bog, flourish only in marshy and boggy ground; those of the parched desert and of the cloudy mountain, each in its fitting locality. Thus the soil and its occupant seem to have been made for each other; and hence one source of that astonishing variety exhibited in nature.

There are still more remarkable deviations among the plants of different countries remote from one another; even where the circumstances of climate and of soil are in every respect alike. The plants of the Cape of Good Hope, for instance, differ exceedingly from those of the south of Europe, though the climate and much of the soil be not dissimilar. Often, on the same continent, nay, on the same ridge of mountains, the plants on the opposite sides have no resemblance. "Thus, in North America, on the east side of the rocky mountains, *Azaleas*, *Rhododendrons*, *Magnolias*, *Vacciniums*, *Actæas*, and *Oaks*, form the principal features of the landscape; while on the western side of the dividing ridge, these genera almost entirely disappear, and no longer constitute a striking characteristic of the vegetation."*

In general, the plants of America are different from those of the old world, except towards the north, where, as it might be expected from the near approximation of the two continents, many individuals are common to both. The plants of islands, and those

* Lindley's Introduction to Botany, page 489.

growing in isolated situations are often quite peculiar. Thus the plants of New Holland, with comparatively few exceptions, differ from those of all the rest of the world; and, "of sixty-one native species, in the little island of Saint Helena, only two or three are to be found in any other part of the globe."* These facts are quite inexplicable upon any known principles; and are calculated to excite a more than ordinary degree of attention, as being solely referrible to the will of the Great Creator; who has chosen to provide infinite diversity where all might have been uniform and monotonous; and has thus rendered more conspicuous his wisdom, his power, and his goodness.

2. *Of the Influence of Climate on Vegetation.*—The climate of a place, as has been before shown, independently of minor local causes, is influenced chiefly by the two following circumstances:—the Latitude of the place; in other words, the general portion of heat and light which it receives from the sun;—and its height above the surface of the sea: by which circumstance of elevation, the heat at least received from the sun, is liable to be varied as much as by latitude; but the variation is according to other laws than those which depend on mere latitude, indeed, according to laws which vary in different latitudes.

Every one is acquainted with the general fact of the difference between the plants of warm and those of cold countries; between the plants that grow on plains, and those that grow on mountains. Thus, "in the countries lying near the Equator, the vegetation consists of dense forests of leafy *evergreen trees*, *Palms*, and *arborescent Ferns*, among which are intermingled *epiphytal herbs*, and *rigid Grasses*. There are no verdant meadows, such as form the chief beauty of our northern climate, and the lower orders of vegetation, such as *Mosses*, *Fungi* and *Confervæ* are very rare. As we recede from the Equator, the plants above mentioned gradually give way to *trees* with *deciduous* leaves; rich meadows appear, abounding with *tender herbs;* the *epiphytal Orchideæ* are no longer met with, and are replaced by terrestrial fleshy-rooted species; *Mosses* clothe the trunks of aged trees; decayed vegetables are covered with parasitical *Fungi;* and the waters abound with *Confervæ*. Approaching the Poles, trees wholly disappear; *dicotyledonous* plants of all kinds become comparatively rare; and *Grasses* and *cryptogamic* plants constitute the chief features of the vegetation."†

Changes not very dissimilar are observed in the vegetation at different heights on the mountains of warm climates. Thus, at

* See Principles of Geology, by C. Lyall, vol. ii. where this interesting subject is considered in detail.

† Lindley's Introduction to Botany, page 484.

the base of the celebrated Peak of Teneriffe, the plants have all the distinguishing characters of those of Africa. There flourish the succulent *Euphorbia*, the *Mesembryanthema*, *Dracœna*, &c.: also the *Date palm*, the *Plantain*, the *Sugar-cane*, and the *Indian-fig*. A little higher, grow the *Olive tree*, the *fruit trees* of Europe, the *Vine*, and *Wheat*. Then succeeds the woody region of the mountain; where from the numerous springs the ground is always verdant. In that region is seen a profusion of beautiful evergreens: such as various species of *Laurel*, one of *Oak*, two species of *Iron tree*, an *Arbutus*, and several others. Next above is the region of pines, characterized by a vast forest of trees resembling the *Scottish fir*, intermixed with *Juniper*. Then follows a tract remarkable for the abundance of a species of broom. At last the scenery is terminated by *Scrofularia*, *Viola*, a few *Grasses*, and *cryptogamic* plants.*

The proportions which different groups of plants bear to each other, vary exceedingly in different latitudes. An interesting table given in the Appendix, slightly altered from Humboldt, exhibits the proportional amount of some natural groups of plants to the whole mass of vegetation in the zones mentioned; and will enable the reader to understand the relation of vegetable forms to the greater or less distance of their place of growth from the Equator. The arrangement is so obvious as scarcely to require explanation. Thus in the equatorial zone, between 10° north and 10° south latitude, the first group, including *Ferns*, *Lichens*, *Mosses*, and *Fungi*, constitutes on the plains only 1-15th, but on the mountains 1-5th of the whole number of plants that exist in that zone. While in the temperate zone the proportion of the first group of plants is at least one-half of the whole number, and in the frigid zone, the entire vegetation consists of plants of that group. The distribution of the other groups is equally remarkable.

From this table we learn many interesting particulars in addition to what has been already stated regarding the distribution of plants over the surface of the globe. We may notice especially the striking difference between the Flora of the Old and that of the New World, in corresponding parallels of latitude. These differences, in a great many instances, are undoubtedly referrible to the unknown causes to which we have before alluded. But in other instances, they are obviously connected with the difference of temperature that prevails in the two continents under the same parallel. Before we proceed, let us dwell a little longer on the consideration of these beautiful arrangements.

In Tropical countries alone, beneath a vertical sun, do we see vegetation in all its glory and magnitude. There, the form, the

* Humboldt.

colour, and the odour of plants are developed to the utmost; and where else could they be so developed? where else could the majestic palm rear its towering stem, and send forth its gigantic leaves? where else could we expect to find groves ever verdant, blooming and productive? Amidst eternal summer, all this is in character; forests denuded of their leaves, and for half the year assuming the appearance of death, would in such a climate be perfectly incongruous. But in countries remote from the Equator, and in which, during many months, the temperature is more or less depressed, a vegetation thus incessantly active could not exist nor would it be appropriate. Accordingly, the palm tribe, and many of the more distinguishing productions of the Tropics become gradually fewer in number as we recede from the Equator, and at last give way entirely to deciduous plants: that is, to plants endued with the power of *hybernating*, or sleeping, as it were, in the colder season; and which vegetate only during the warmer portion of the year. And here we have displayed another of those admirable provisions, which at once strike us irresistibly as being the effect of design! In Tropical countries, where the seasons are uniform, and where there is no cold to injure, the leaf buds of plants are without covering or protection, and are freely and confidently exposed to the atmosphere. But in climates where the seasons change, and where vegetation is liable to be suspended by the cold, the leaf buds exhibit a structure remarkably different. Developed in the latter end of summer, or autumn, they are almost invariably provided with *tegmenta* or coverings; within which, during their period of torpor they are cradled, safe from cold and from accident!

As we advance still further to the north or to the south, where the winter becomes more severe and of longer continuance, deciduous plants in their turn diminish both in number and in magnitude; and after having shown themselves under a variety of stunted forms, are at length almost entirely superseded by a few coarse grasses and lichens. Yet even here design is apparent. These hardy natives of the poles are, from the simplicity of their structure, wonderfully adapted to the climate of the region they occupy; in which alone they will flourish, and for which alone, therefore, they have been expressly created.

Though it be generally true that plants will grow only in the soil and climate adapted for them; yet, as if intentionally to evince His power, the Great Author of nature has created some manifest exceptions to this rule. All organized beings have been more or less endowed with the faculty of accommodating themselves to circumstances. In the larger number of plants this faculty scarcely exists; but in some it is much stronger; and in others, constituting the exceptions to which we allude, the extent

of the accommodating faculty is almost incredible. In general, plants that are the natives of peculiar soils, and of extreme climates, are the most impatient of change; while the natives of ordinary soils, and of temperate climates, have a wider range of growth. The exceptions to the rule of adaptation are chiefly among plants that are natives of such soils and climates. Thus "the *Samolus Valerandi* is found all over the world, from the frozen north to the burning south; associated here with *Birches*, and similar northern forms, and there mixed with *Palms* and the genuine denizens of the tropics. The number of plants, however, which can thus accommodate themselves to all circumstances and climates is limited; while those which readily naturalize themselves in climates similar to their own, are, on the other hand, numerous. Of the latter, indeed, examples present themselves at every step. All the hardy plants, for instance, of our gardens may in some sort be considered of this nature; for although they do not grow spontaneously in the fields, they flourish almost without care in our gardens. The *Pine apple* has gradually extended itself eastward from America, through Africa, into the Indian Archipelago, where it is now as common as if it were a plant indigenous to the soil; and in like manner the *Spices* of the Indies have become naturalized on the coast of Africa and the West India islands." To this property of naturalizing themselves, no doubt, is to be referred, in a variety of instances, the presence of the same plants in different countries. For though, as we have just stated, the Flora of different countries is generally different, yet in almost all instances, some plants exist which are found in other countries. Thus, "above 350 species are said to be common to Europe and North America; and even among the peculiar features of the Flora of New Holland, Mr. Brown recognized 166 European species. The presence of many such strangers may undoubtedly be referred to the agency of man and other animals; to currents in the ocean, to winds, and a variety of natural causes." While "the presence of others, seems inexplicable on any other supposition than that they have been created in the places where they now exist."*

Hitherto we have considered plants only in relation to the soil and to the climate in which they grow; and have not entered into details respecting all the beautiful arrangements, by which their growth has been accomplished. The consideration of these arrangements belongs to the Physiologist, the Botanist, and the Geologist, with whose duties we wish as little as possible, to interfere. There is, however, yet one point of view in which our

* Lindley, Introduction to Botany, p. 501.

argument naturally leads us to consider vegetation ; namely, as forming the link, by which animals are connected with the earth ; in other words, as furnishing to animals the means of subsistence.

One circumstance, which, perhaps more than any other is calculated to arrest our attention with respect to vegetable productions in general, is their vast *profusion* in every sense of the term ; whether we contemplate their variety, their magnitude, or their number. Thus the numerous and varied plants growing in tropical climates are equally remarkable from their size, the luxuriant foliage, and the exuberance of their roots and seeds. Let us take, for instance, the palm tribe. It has been estimated that there are a thousand species of palms ; and though the number actually known to exist is by no means so large, yet late discoveries seem to render the estimate not improbable. In many of the palm tribe the developement of the form, and the quantity of flowers and fruit is altogether extraordinary. Among others, the species which yields the well known *Cocoa nuts* grows to the height of eighty feet; each plant flourishes for a century, and, during the greater part of that time, continues to produce annually at least a hundred of these large nuts. Yet the cocoa nut species may be considered as one of the least productive of the palm tribe : for every bunch of another species, the *Seje* palm of the Oronoko, bears as many as 8000 fruit ; while a single spatha of the *Date* palm contains 12,000 flowers ; and in a third species, the *Alfonsia Amygdalina*, there is the enormous number of 207,000 flowers on each spatha ; or 600,000 on a single individual plant !

In superlative exuberance, however, the Palm tribe must yield to the *Banana*, or Plantain, another inhabitant of tropical countries. The fruit of this plant is often a foot in circumference, and seven or eight inches long : it is produced in bunches, containing usually from 160 to 180 fruit; and each bunch weighs from 66 to 88 pounds avoirdupois. As Humboldt has remarked ; the small space, therefore, of 1000 square feet, on which from thirty to forty Banana plants may grow, will, on a very moderate computation afford, in the course of a year, 4000 pounds weight of fruit ; a produce 133 times greater than could be obtained from the same space, if covered with wheat ; and 44 times greater than if occupied by potatoes. The *Orange* tree may be mentioned as another instance of extraordinary fecundity ; thus a single tree at St. Michael's has been known to bear in a season 20,000 oranges fit for packing, exclusively of those damaged and wasted, amounting to at least one-third more. An example to the same effect, but of a different kind, is the *Sugar* cane, which furnishes an unlimited supply of saccharine matter in its purest form ; while

various roots, as those of the *Cycas Jatropa*, and many others abound equally in farinaceous matters.

As we withdraw from the Equator into the regions of hybernating plants, vegetation is seen on a much less magnificent scale; though in the temperate climates, and even where we might expect to find utter sterility, *number*, in some degree, compensates for *magnitude*. Thus, instead of the single stupendous tuft of the palm, we have the numerous congregated buds of our deciduous trees; instead of the gigantic and solitary grasses of the torrid zone, we have the smaller and gregarious varieties. Some of these varieties, as the *Cerealia*, or Corn tribe, with their myriads of seeds, give us an inexhaustible supply of farinaceous aliment; while others, as the Grasses properly so called, clothe our meadows with verdure, even to extreme latitudes; and are equally productive of matter purely herbaceous. In the warmer parts of the temperate zone, the Olive and the Vine afford the oleaginous and the saccharine principles under a form, different, but not less useful than the oil and the sugar of the tropics; while in the colder parts, various seeds, and hardy fruits, produce an ample store of the same valuable articles, though in a condition still further modified.

In the preceding sketch we have intentionally kept out of view the existence of animals, that we might here ask the question, Of what use is all this amazing exuberance of superfluous matter throughout the globe? The adaptation of plants to the climates in which they flourish is evidently the work of an intelligent Creator. But is this apparent waste of materials and of labour to be reconciled with the same wise agency? Surely, the mere existence of vegetation did not require such prodigality. Seeds, for instance, need not have been enveloped in bulky fruits; nor need they have been produced by myriads: and all that foliage, all those flowers, and roots, in such amazing profusion, of what use are they; why where they so created? Regarding vegetation as a thing simply adapted to climate, and existing for its own sake alone, the question scarcely admits of a rational answer. But, considering at the same time the existence of animals, and viewing these superfluities as the means by which animal existence is principally upheld, every difficulty vanishes, and the splendid design of the whole wonderful scheme becomes at once apparent. We are thus brought to the consideration of animal existence.

Section II.

Of the Distribution of Animals over the Globe.

Animals have been so constituted that food is to them indispensable: they can, therefore, exist only where their food has been supplied by nature. On land, at least in the warm and temperate climates, by far the greater proportion of animals derive their subsistence, either directly or indirectly, from the vegetable kingdom. For those animals that are themselves carnivorous, prey on vegetable feeders much oftener than otherwise; and are thus remotely dependent on vegetables. Of the habits of animals living in the sea, and thus concealed from our view, we know still less; but in general they appear to prey on each other, the stronger, as is usual, devouring the weaker.

We have seen the wonderful diversities that prevail among vegetables, in different situations and climates; and it may be truly said that the diversities among animals are not less numerous, and are even more extraordinary. Thus, in every climate and soil, almost every herb has its appropriate inhabitant; some little being, that comes into existence, passes its ephemeral life, and dies on that plant; to which, therefore, that plant constitutes the world. Nay, in general, even different parts of the same plant have each its separate occupants, one feeding on its fruit, another on its flowers, a third on its leaves, perhaps a fourth on its very woody core. This almost infinite diversity, and infinity of number, are principally confined to the smaller animals, or insects. As animals increase in size, the number of species as well as of individuals constantly diminishes. Thus, while there are hundreds of species of the Beetle tribe, and the individuals are countless, there may be considered to be only one Elephant; and while Shrimps are in numbers like the sand on the sea-shore, the Whale is as much a solitary species. This striking difference with regard to numbers has been considered to arise necessarily from a law of nature, and in one respect such an explanation is very obvious; but in another point of view, we may contemplate an admirable evidence of design. It is clear that millions of elephants could not exist, if for no other reason, from want of food; but why should millions of beetles exist? why should these little creatures,—whose life is so transitory, that it consists of little more than of being born, and of dying, whose structure is so frail as to be liable to be annihilated by the slightest accident, who are everywhere surrounded by all sorts of enemies, to many of which they constitute a natural prey,—why, we ask, in spite of all these obstacles and dangers, should these insignificant animals contrive to exist in

the numbers we see them ? No natural law, surely, will explain the appearance of such multitudes. The difficulty requires another solution ; and the only solution that can be offered is *design*— that it was so designed by the Great Author of nature. And how has He effected His purpose of multiplying to such an extent these little animals ? The answer is, simply, by increasing their fecundity. Had beetles, like elephants, brought forth only one young at a time, long ere now, their race would have been exterminated ; but being produced by thousands, some of the numerous offspring chance to escape, and thus the race is perpetuated.

We shall not dilate further on the arrangements that have been made for the existence and preservation of animals, but shall proceed to consider their distribution.

The distribution of animals over the globe may be conveniently treated of under the same heads as the distribution of vegetables ; and, first: —

1. *Of the Differences existing among Animals that live in similar Situations in different Parts of the World.*—The dwelling of animals in the waters is, perhaps, the most remarkable as regards their localities. Now, since, from circumstances formerly stated, the distribution of temperature is very different in the sea from what it is on land ; and since most aquatic animals prey on each other, and consequently in some degree are independent of climate ; the distribution of such animals over the globe follows laws materially different from those which regulate the distribution of land animals. This distribution of temperature more especially affects the distribution of animals in high latitudes ; and must be taken into account at the very outset of this part of our inquiry. We shall, therefore, state concisely the distribution of land animals, and of sea animals, apart from each other.

The distribution of land animals resembles to a certain extent that of vegetables ; for though animals differ from plants, in being endowed with the power of locomotion, yet, as the larger number of animals are dependent on vegetables for their subsistence, they are necessarily confined to those places where their peculiar food may be obtained. This limitation of range is most observable in the case of the smaller animals. The existence of many kinds of insects, especially, is intimately connected with that of certain plants. In every tribe of animals, however, there are species that occupy very different localities. Thus, in the same tribe, some species dwell on the mountains, others on the plains ; some are most numerous on the sea-coast, others live on trees, while there are others that burrow beneath the surface of the ground. All these diversities, in regard to residence, are probably influenced, like many others, by the greater or less degree in which

the locality affords the means of obtaining subsistence. But, in many animals, there is also a wonderful adaptation of structure to the place they inhabit; proving, beyond a doubt, that the distribution of animals has been arranged by design; and that they form but a part of the great symmetrical whole of creation.

In animals that dwell in the water, the same peculiarities of habitude are observable, as in those that dwell on the land. Thus, it is perfectly known that many animals can live only in salt water; others only in fresh. Some prefer the deep and open sea, others are met with only in shallow water, or at the mouths of rivers. Of those that flock to the coast, some shun turbid water, others burrow in the mud. In short, though the habits and adaptations of aquatic animals can be less satisfactorily ascertained; there is every reason to believe that they are at least as wonderful, as those of the occupants of the land.

There is an equally striking diversity in the animals, as in the plants, of similar localities and climates in different parts of the world. Thus, in the old world, in the analogous climates on the north, and on the south of the equator, though many genera exist in common, yet the species are totally different. For instance, the northern hemisphere possesses the *Horse*, and the *Ass*; while, in the south, these species are represented by the *Zebra* and the *Quagga*. In the southern hemisphere, there also exist many species which are quite peculiar; as the *Giraffe*, the *Cape Buffalo*, and a variety of animals having the *Antelope* form. So, likewise, the animals of the old and those of the new world are, in general, quite distinct; unless, perhaps, towards the north, where the two continents approximate; and where, in consequence, there are some species common to both. Thus the *Elephant*, the *Rhinoceros*, the *Hippopotamus*, the *Giraffe*, the *Camel*, the *Dromedary*, the *Horse* and the *Ass*; also the *Lion* and the *Tiger*, and various species of *Apes*, *Baboons*, and other animals, with which we are familiar in the old world, were not found in America. On the other hand, the American species, the *Lama*, and the *Peccari*; and among carnivorous animals, the *Jaguar*, or American tiger; also the *Agouti*, the *Paca*, the *Coati*, the *Sloth*, and others, were equally unknown in the old world. Again, the animals of New Holland differ, like its vegetation, not only from all those of our continent, but from those of all the world besides. In New Holland, there are more than forty species of marsupial or pouched animals, of which the *Kangaroo* is that with which we have become best acquainted; while everywhere else, there is hardly a known instance of a pouched animal. Nor are these differences confined to the more perfect animals. They are even more striking as we descend in the zoological scale. Thus among birds; the individual species of the *Parrot*

tribe, that are found in America, differ altogether from those of Africa; and those of Asia differ from both. The minute and beautiful family of *Humming birds* is peculiar to America. While the species of the common *Grouse* of this country is met with in no other part of the known world.

From the class of reptiles, may be mentioned the Great Saurian, or Lizard tribe. Thus the *Crocodile* of the Nile is entirely different from the *Cayman* of America; and even from the *Gavial* of the Ganges. In the division of snakes, too, the *Boa* of India differs from the nearly allied *Python* of America; and of the poisonous varieties, the *Rattlesnake* is peculiar to America, the *Cerastes* to Africa, the *Hooded snake* to Asia. As we have already stated; the diversities among insects are still more numerous and remarkable than among the larger animals. To enter into details would be endless; we shall therefore mention only one of the best known and widest extended of all the insect tribe, viz. our *common Bee.* This insect did not exist in America, or in New Holland; though it is found in all parts of the old world; the wax and honey of Europe, Asia, and Africa being obtained from species having a close resemblance to each other.

Nor are these differences confined to land animals; the inhabitants of the waters are equally diversified. Thus the *Whales* of the northern ocean are quite unlike those of the south; as are the *Seals*, and other analogous animals in the polar regions. The fishes of different seas, also, not only when far apart; but even of some which freely communicate, have fish exceedingly dissimilar. Thus the fishes of the Arabian Gulf are said to differ entirely from those of the Mediterranean; notwithstanding the proximity of these seas. Nor do these remarks apply only to the larger fish in these seas, but hold equally with respect to their testaceous and molluscous species.

Such are a few of the more striking facts with regard to the distribution of animals in similar climates and localities throughout the world. We shall now briefly speak,

2. *Of the Effects of Diversity of Climate on the Distribution of Animals.* In tropical climates, the qualities of animals, as well as those of vegetables, are developed to the utmost; whence arises that harmonious adaptation of all the works of nature, conspicuous, indeed, in all climates, but in Tropical climates more especially. For, where else than amidst the profuse exuberance of the vegetation within the tropics, could the *Elephant*, the *Rhinoceros*, the *Giraffe*, and other large quadrupeds find subsistence? Where else could we expect to see such birds as the *Ostrich* and the *Cassowary?* Such reptiles as the *Crocodile?* such serpents as the *Boa?* To what other part of the world could the magnificent butterflies, the enormous beetles and

spiders be so appropriate. Even among the marine animals of Tropical climates, some display the same wonderful enlargement of size. Thus certain species of the *Crab* and *Lobster*, and various shell-fish, often attain an enormous magnitude. Nor is there a developement of size only, but of every other property in an equal degree. Countries within the tropics exhibit the most beautiful forms—the most splendid colours in nature. There, in short, is the most astonishing display of all those things which seem to be entirely ornamental: as, for example, the singular plumage of the *Birds of Paradise*—the gaudy liveries of many of the *Parrot* tribe—the extraordinary and diversified forms and colours of many insects and shells.

Not only is there in Tropical climates an assemblage of all the concomitants of productiveness, and utility, and embellishment of every kind; in these climates, there is another and not less marked demonstration of the power and the wisdom of the great Creator. Within the Tropics *death*, the last, the inevitable scene, assumes a character as new and diversified as that of the life it terminates. There, rages the implacable ferocity of the Tiger, and of the larger beasts of prey; there, are the fangs of the serpent charged with the most malignant venom; there, even the insects are as formidable as they are numerous. Nor is this intensity of the destroying power incongruous or without an object; but obviously is in perfect harmony with the rest of creation, and with the design of the Creator. The wonderful productiveness of animals in Tropical countries renders unavoidable some checks against their excessive increase: and in devising these, the great Author of Nature has displayed the same attributes that are manifest in all his other works. No one who seriously reflects can doubt either the wisdom or the benevolence of the provision. For why are Tigers and Serpents confined to those parts of the world where their existence is not only accordant, but where, for one great purpose at least, they are even necessary. Surely such limitation could have happened only from design; and the argument is strengthened a hundred fold; when we contemplate the striking display of wisdom and of power exemplified in the singular adaptation of structure in these animals, to their peculiar habits. Thus how wonderfully appropriate is that of the Tiger; and how extraordinary as well as wonderful that of Serpents! Who (unless he had witnessed the fact) could have believed that the animal frame was capable of separating from its juices, and of retaining with impunity, a poison instantly fatal, not only to other animals, but to the animal itself; if again mingled with the juices from which it had been separated!

Nor in all these things is the benevolence of the Deity less

conspicuous than his wisdom. *All must die;* and death from rapacious or venemous animals is probably not in any degree more painful than many other modes of death, which we constantly witness. There is, in truth, to our own narrow and selfish feelings something exceedingly painful in the idea of being torn to pieces by a Tiger, or stung to death by a Rattlesnake; but how many thousands of little mice are destroyed by cats? and how many myriads of unfortunate flies are poisoned by spiders, every day we live? and yet we hardly commiserate them. The question, therefore, is simply a question of degree; and viewing the existence and the destruction of animals, as they ought to be viewed, on the great scale, we find that the whole is perfectly in unison. While in temperate climates we have cats and spiders, designed as checks on over-productiveness; amidst the grandeur and the luxurious developement of the Tropics, the same wise purpose is executed by the Tiger and by the Rattlesnake.

As we advance from the Equator into the temperate climates, the size of animals in general, like that of vegetables, becomes gradually smaller. Like the vegetables, too, the animals of temperate climates are more gregarious than within the Tropics. Hence *number*, as among vegetables, compensates in some degree for diminished *magnitude*. The two kingdoms of nature therefore are beautifully analogous; for the gregarious grasses, which, as we before observed, form so marked a feature in the vegetation of temperate climates, constitute in one shape or other the principal food of the gregarious tribes of animals. Thus the whole cattle tribe—The *Ox*, the *Sheep*, the *Goat;* the different varieties of *Deer;* the *Rabbit* and *Hare;* also the *Horse* and the *Ass;* with a multitude of other well-known animals, of a similar character, are natives chiefly of temperate climates, and obtain their nourishment almost entirely from the grasses. Among birds, the numerous species of the Gallinaceous, or Fowl tribe, may be said to derive their food from the same source. Therefore, as regards the existence of animals, the gramineous tribe of plants is more important than perhaps any other; and could not be annihilated, without the destruction of the present order of living beings.

As further examples of animal species indigenous to temperate climates, may be mentioned the *Canine* species and those allied to it, most of which are more or less carnivorous; also the *Hog*, and a variety of other animals that need not be here enumerated. The Hog tribe, as is well known, are omniverous; but in their natural state, they feed principally on the seeds and roots of plants. Among birds peculiar to temperate climates are various tribes of *Water-fowl* that subsist on fish and on insects. Of the

smaller land birds, the various *Songsters* offer a remarkable contrast to those of similar form within the Tropics; not only from their more melodious notes, but from the simple colouring of their feathers. In temperate countries the *Insects* are still exceedingly multiplied; though, in general, like the other animals, they are much smaller in size than those within the Tropics; their forms, their colours, and other peculiarities also are much less remarkable.

As we advance toward the Poles, the animals of temperate climates are observed gradually to decline in number. The vegetable feeders become reduced to a few hardy species; and at length in the remote north and south scarcely any vegetable feeders remain. So far as shrubby plants continue to grow in these inhospitable regions, individuals of the *Squirrel* tribe find subsistence on their seeds and roots. But the most remarkable herbivorous animal is the *Reindeer;* whose principal food is afforded by nature in a species of moss peculiar to very cold climates. Those that exist beyond, are either carniverous or piscivorous. The *Arctic Fox* and the *Bear* are familiar instances, as terminating the Zoological series, viewed in connection with the influence of climate.

We have, in the last place, to notice what is most remarkable in the distribution of *Marine* animals.

For the reasons before stated, the general temperature of the ocean differs considerably from that of the land. Owing to this difference of temperature, and to the peculiar mode of subsistence of marine animals, which find their prey chiefly in the waters they inhabit; the distribution of these animals varies much, as compared with the distribution of animals that are entirely terrestrial; particularly within the frigid zone. It is true, indeed, that in all climates, the denizens of peculiar localities, as fresh water species and those that resort to the shallows on the coast, are influenced by the climate nearly as much as land animals: and within the Tropics, this influence extends in some degree even to the species that dwell on the wide ocean. But far to the north, and to the south, such species are influenced in a manner altogether different. Thus the largest of known animals, the *Whale*, and of course those other animals that become its prey, roam through the utmost Polar seas; where on land the intensity of the cold would prevent the existence of any animal whatever. In that climate the whale is enabled to live, solely on account of the greater warmth of the Polar ocean, as has been formerly explained. Among the larger inhabitants of the ocean in Tropical climates, may be mentioned the *Shark* tribe; which in respect of ferocity and voraciousness, may be classed with the tiger, or any kindred species on land. The influence of climate on marine animals is further shown,

as we have said, by the enormous size of many of the Tropical shell-fish and mollusca. The colouring of these and also of other productions of the Equatorial seas, often exhibits so much lustre and beauty, as to rival the most splendid of the feathered race. In temperate climates, and from the equal temperature of the sea, even within the frigid zone; it is remarkable that fish, like terrestrial animals, are much disposed to be gregarious. The shoals of *Herring*, *Mackarel*, and other well known visitants of our coast, are familiar examples of the gregarious tendency. The *Salmon* and the *Sturgeon* may be adduced as instances of fish inhabiting chiefly the rivers of the temperate and colder countries. While in the same climates, instead of the magnificent *Pearl oyster* of the Tropics, there appears our common *Oyster*, so diminutive and unsightly, yet so profitable to man.

We have thus seen that animals, like plants, have in general been adapted to particular climates. The numerous cold-blooded animals of the Tropics—even the warm-blooded Tiger itself, amid the Polar snows would instantly perish. The Arctic bear would be not less unable to live, under the scorching rays of a vertical sun. Yet though adaptation to one climate be the general law regarding animals as well as plants; some species of animals have as remarkably as some species of plants, the faculty of accommodating themselves to all climates. These species, like the plants similarly endowed, are for the most part natives of temperate climates; the transition from such climates to either extreme, being much less violent than from one extreme to the other. Thus our domestic animals, that have been successively introduced into the New World at various periods since its discovery, are now, in incredible numbers, spread over the whole of that vast continent, from Canada to Paraguay. The greatest increase has been of the Horse, the Ox, the Sheep, the Goat, the Dog, the Cat, and the Hog. The Rat, too, though an unwelcome intruder, has been not the least prolific. The different varieties of domestic Poultry have multiplied to an equal extent. Even insects have been introduced, and spread in like manner, as is well known to horticulturists.

Like plants, most animals also are readily domesticated, and thrive in climates similar to those of which they are natives. The most striking instance is the Rein-deer; so lately as in the year 1773 introduced into Iceland, and now exceedingly numerous in the interior of that country. From these powers of accommodation to climate, from the agency of man, and from accidental causes; the distribution of the larger animals over the globe has, in comparatively recent times, been very much modified. Nor is there any reason to believe that the distribution of these animals is yet stationary; but, on the contrary, that their distribution will undergo still further changes.

Among the more remarkable habits of animals, may be noticed the *migratory* propensities of certain species. The migration of land animals is, of course, always much limited, and may be entirely prevented by natural obstacles—the asperities of the earth's surface—sands—deep rivers—or other large accumulations of water. But many birds and even insects, possessing powerful locomotion, and whose course is through the air, may literally be said to follow the sun in their migratory progress. It is hardly necessary to state, as examples, the birds of passage, so well known as the Swallow and the Cuckoo. These birds during the summer months visit our northern climate, and feed on insects, whose multiplication would otherwise be boundless. Having fulfilled their office here; on the declination of the sun, they again retire to the south; and are succeeded by different birds from countries still further north. Such are the Woodcock and others, which escape to our shores from the rigorous cold of a Polar winter. Nor is migration confined to the higher classes of animals. The wonderful powers of flight possessed by many insects, enable them to travel over an immense extent of country. The Locust and the Ant tribe are familiar examples. These insects occasionally migrate in countless swarms from the lands to which they are indigenous, and lay waste others far remote.

Equally remarkable is that habit of animals termed *Hybernation*. Like the plants of temperate climates, some animals have the faculty of passing the colder season of the year in a state of sleep. The Hedgehog and the Dormouse may be mentioned as examples of quadrupeds possessing this faculty. Additional instances might be given in all the classes of animals. Nearly allied to Hybernation, is that remarkable instinct which guides many of the inferior animals to deposit their eggs in the earth, or in some other place of safety; that they may be preserved during the season of diminished temperature. This instinct is particularly observable in insects whose lives are ephemeral, or are, at the utmost, prolonged for a summer.

There is yet another circumstance that remains to be noticed, as being connected with the adaptation of animals to the climates in which they live; namely, the *Clothing* or covering with which they have been supplied by nature. Every one is acquainted with the general fact, that wool, fur, eider-down, and similar articles, are obtained for the most part, not from the copious source of every superfluous production, the countries within the tropics, but from the cold, and comparatively unprolific regions of the temperate and of the frozen zones; where they have constituted the appropriate vesture of different animals. Perhaps, in the whole range of creation there is not anything more calculated to excite our admiration. However we may view these means of guard-

ing animals from being injured by the cold; whether as a part of that conservative faculty with which animals have been endowed, and by which their existence is maintained; or as an immediate act of Providence; still the adaptations are so striking and obvious, as to render it impossible to doubt for a moment, that they have all been contrived for the purpose which is accomplished; and that they are the results of foreknowledge and of design.

We have thus given a rapid sketch of the distribution of animals over the globe. In this sketch we have endeavoured to point out the wonderful adaptations of the several classes of animals to the circumstances in which they are placed; together with the beautiful symmetry and equilibrium exhibited in zoology, not less than in the arrangements of inanimate matter. Throughout we have intentionally, and as far as was possible, avoided those details, the consideration of which belongs to other departments. But it has been our aim to state such prominent facts, as appeared best calculated for the elucidation of our argument. In particular, it has been our desire to show—how number among the weak is made to compensate for magnitude among the strong; how exuberance in one species is made to contribute to the existence of another; how ornament and boundless profusion characterize the countries within the tropics, while the temperate climates are not less distinguished by utility and capacity for change; how, even in the rigorous and barren neighbourhood of the Poles, where life becomes a struggle for existence, animals have been expressly furnished with clothing appropriate to these regions;—in short, we have endeavoured to demonstrate, how every animal, in every climate, has its day; and by some peculiar contrivance, has been enabled to maintain its rank in creation, and to assist in preserving the general equilibrium.

Hitherto we have considered the works of nature without reference to *Man*. For aught we can see to the contrary, they might all have existed, and every arrangement and operation might have been very nearly, if not exactly, the same as at present; though man had never been called into being. But still, for a moment longer, keeping man's existence out of view; let us, as under a former division of this Treatise, inquire, what would have been the *use* of all this elaborate design, without an ulterior object. Would an intelligent Creator have made such a world, and have left it thus incomplete? It is evident that the other beings inhabiting this earth, live and die, without in the slightest degree comprehending the vast system of which they constitute a part. Hence they are merely unconscious agents, from which their Maker, while he has furnished them with the instincts necessary to their existence, and has awarded equal justice to all,

has yet chosen to withhold the privilege of reason. That a Creator, evidently as benevolent as he is wise, might, for his own gratification, have made such a world, and without any other inhabitants, is indeed possible. But, even admitting that possibility, the probability surely is, that he would not there have finally "rested from his labour." His benevolence would have prompted him to communicate to other beings a portion of the gratification, which he himself is supposed to derive from the contemplation of his works. In the beautiful world which he had created, he would have wished to see *one* being at least, capable of appreciating to a certain extent his design and his objects. Such is a plain inference deducible from the manifest attributes of the Creator; and what is the fact? Is not man such a being as we have supposed? Throughout the world, though perfectly independent of him, is there not a clear foretoken of his existence? Has he not been placed at the head of that world, so obviously prepared for him, and thus constituted "the Minister and Interpreter of nature?" Surely no one will be inclined to doubt that such is the situation of man in the world. Equally undeniable, is the striking accordance of these deductions from the view of external objects, with what is written of the origin of man by the sacred historian: "and God said, that it (the world which he had prepared) was good. And God said, Let us make man in our own image, after our own likeness, (that is to say, endowed with reason and with the power of reflection). And let him have dominion over the fish of the sea, and over the fowl of the air, and over the cattle, and over every creeping thing, that creepeth on the earth."

We thus arrive at another, and to us the final step in the great design of the Omnipotent: the creation and the faculties of Man.

Section III.

Of the present Position and future Prospects of Man.

The consideration of the faculties of man, and of his position in the world he inhabits, belongs, in all its details, to another department. We advert to these subjects here, with the view only of completing our sketch of the physical relations of animated beings. The observations we have to offer will be comprised under two heads:—as to the means, by which man has acquired and maintains the *ascendency* he enjoys:—as to the conclusions to be drawn, from man's *elevated position*, and from his superior *intellectual character*.

With regard to the means by which man has acquired and

maintains his *ascendency*, it may be observed, that these means are quite peculiar; and far from being such, as at first, perhaps, we might deem conducive to such an object: though when once known and understood, the beautiful design and harmony they evince, immediately become apparent.

The supremacy of man has *not* been the result of his own personal strength, nor is it so upheld. On the contrary, many animals are larger and more powerful than he is; while few of his size, are naturally so incapable of self-defence; or during so long a period suffer from the dependent helplessness of infancy and of old age. Neither is his frame superior in external adaptation to climate: for while nature has furnished other animals with clothing appropriate to the temperature in which they live, man has been brought into being absolutely naked; and moreover remains so, in every climate he inhabits, from the Equator to the Poles. Lastly, the pre-eminence of man has not been owing to his more extensive range of diet; or to his greater ability for assimilation: for though man be omnivorous in one sense of the term, he is not omnivorous according to the application of the term to other animals; that is to say, man does not eat indiscriminately of every kind of aliment, in the state in which it is afforded by nature; for even in his rudest condition, he adopts some process of cookery. How then has man gained the high station which he occupies? The answer is simply—by his *Reason*. Man has been created a reasonable being; and this endowment amply compensates to him for the want of the animal requisites of strength—for deficiency of natural covering—and for his restricted ability in assimilating his food. By his reason he is enabled to command the strength of the elephant; to choose from every production of nature whatever is adapted for his clothing, and thus to array himself according to his pleasure, or the exigencies of the climate in which he resides; to extract wholesome nourishment from the most unpromising, even from the most deleterious articles. There was no necessity, therefore, why man should himself be as unwieldy as an elephant; or be encumbered with any vesture that in some situations might be oppressive; or be able to digest, without culinary preparation, any coarse and intractable substances. Thus, mere animal endowments not being requisite, the Creator's wisdom has been displayed in another manner, and with a wider scope. In furtherance of his design, He has limited the bulk of the human species to that happy medium, combining strength with convenience; and to an organization delicate and sensitive in the highest degree, but nevertheless accommodating, He has superadded a form at once peculiar, appropriate, and beautiful!

When speaking of temperate climates, we remarked, that they

seemed to be characterized by the utility of their productions; and that the plants and animals of these climates, generally possessed greater powers of accommodation than those of either of the extreme climates. Now Man, by an express arrangement of his Maker, has apparently been constituted a native of temperate climates; and only in these climates can his powers be said to be completely developed. Within the tropics, indeed, human existence is flourishing; for there the immediate bounty of Providence affords to man a copious and admirably adapted nutriment. Yet in the midst of that profusion, and without any adequate motive to call forth exertion, his reason too often languishes; while his animal tendencies predominate; and his life is spent in apathy and in sensual gratifications. On the other hand, under the cheerless sky of the frigid zone, imperfectly nourished by scanty and unsuitable food, the powers of his mind, like those of his body, are stunted; or are engaged solely in combating the rigours of his situation. But in the temperate climates the evil consequences of both these extremes are avoided, while the beneficial influences of climate remain. Urged by the stimulus of necessity, and at the same time having at his command the astonishing capability of nature, man is, in temperate climates, surrounded by motives of every kind, and his faculties thus attain their utmost developement. As familiar examples of the effect of this expansion of the human reason, let us view man under the three aspects to which we have before alluded; namely, with reference to his *strength*, his *food*, and his *clothing*, inclusive of his *habitation*.

In the first place, with regard to his strength. The strength of man is not only that which is his own, almost infinitely magnified by ingenious mechanical devices of every kind, and of every degree, up to the stupendous agency of steam; man has, moreover, subdued to his service many of the larger animals, while those which he cannot so appropriate, he destroys. As weapons, he wields every instrument offensive and defensive, from the rude but effective club or arrow, to the warlike engines to which he has applied the discovery of gunpowder. Whatever his wants require, he obtains by tools; from the humble spade, to that perfection of machinery, which almost rivals the operations of intelligence itself. In the next place, view man with reference to his food: what wonders has not his reason enabled him to achieve among the fellow inhabitants of his own temperate climate. In the vegetable kingdom, let us consider the astonishing mutations and increase of the *cerealia*, or corn tribes; the transformation of the sour and forbidding Crab into the rich and fragrant Apple; of the harsh and astringent Sloe into the delicious Plum; of the coarse and bitter sea-side *Brassica* into the

nutritious and grateful Cauliflower: all which changes, and numerous others of a like kind, have been effected by man. Nor have the transformations which he has produced among animals been less wonderful than those among vegetables. All the numerous varieties of cattle, of sheep, of horses, of dogs, of poultry, and of all the other animals reared as food, or for any purpose domesticated, have sprung from a few wild and unattractive species; and have been made what they are, in a great degree, by his intervention. Moreover, the most useful of these varieties of animals have been transported by man into every region of the globe, to which he has himself been able to penetrate. Lastly, in the clothing and habitations of man, the surpassing influence of his reason is equally conspicuous. For covering his naked body, a surface of considerable extent is necessary; larger, indeed, than is presented by any natural texture, unless, perhaps, by the skins of other animals, or by the leaves of some plants; which therefore, in the rudest states of society, usually constitute his only dress. But by the art of *weaving*, he has been enabled to produce garments of any size, and from materials that would seem the least fitted for such conversion. Thus man can not only clothe himself in any manner, and according to the temperature of the climate in which he lives; but he can associate with the articles of his dress every species of ornament which his fancy may dictate. His choice of materials for the construction of dwellings is not less extensive than that of his clothing. As climate and other circumstances may require, he abides in the humble cabin, or in the splendid palace; in the temporary hut, or in the enduring castle, formed to withstand alike the tempest of war, and of the elements.

Such is man, and such are a few of those great changes in this world, which, under the guidance of his reason, he has had the power to accomplish. And what a splendid evidence of design and of preconcerted arrangement on the part of the great Creator is thus exhibited, by viewing the inherent properties of matter, and its various conditions, with reference to the works of man. Had water, for instance, not been constituted as it is, man could never have formed the steam engine. Had not the productions of the temperate climates been formed with that capability for change, by which they are so much distinguished, man could never have so moulded them to his uses, by altering their character. There was no reason why such properties should have been communicated; there was even no reason why the objects in which these properties exist, should have been created. But they have been so created; and what are we to infer? No one surely will contend that they have been the result of chance, or

have been created without an object. They must therefore have been created with design; and if with design—most obviously with design having reference to the being man, *not yet in existence.*

Thus far we have considered the state at which the earth has arrived, and man, an animal endowed with reason, placed as its chief inhabitant. But we may yet extend our view to the prospects in *futurity.*

We have seen that this earth has not suddenly emerged from chaos to its present condition; but that by a succession of violent and disruptive changes, it has been progressively brought into different conditions, and progressively tenanted by higher orders of beings. We, the last of the series, in our own creation and in the faculties with which we have been endowed, behold the most striking exemplification of the wisdom, and of the power of the Deity. But does the great design abruptly terminate here? Has this earth arrived at the ultimate stage of its existence? Have its inhabitants attained the utmost perfection of which they are capable? Are there not further convulsions, and still higher orders of beings in contemplation? The answers to these questions are known only to the great Author of the universe, and concern us not. There is one question, however, connected with this subject, in which we are deeply and personally interested—*What is to become of man?* Is the being who, surveying nature, recognizes to a certain extent, the great scheme of the universe; but who sees infinitely more which he does *not* comprehend, and which he ardently desires to know;—is he to perish like a mere brute—all his knowledge useless; all his most earnest wishes ungratified? How are we to reconcile such a fate with the wisdom—the goodness,—the impartial justice—so strikingly displayed throughout the world by its Creator? Is it consistent with any one of these attributes, thus to raise hopes in a dependent being, which are never to be realized? thus to lift, as it were, a corner of the veil—to show this being a glimpse of the splendour beyond—and after all to annihilate him? With the character and attributes of the benevolent Author of the universe, as deduced from His works, such conceptions are absolutely incompatible. The question then recurs—What is to become of man? That he is mortal, like his fellow creatures, sad experience teaches him; but does he, like them, die *entirely?* Is there no part of him, that, surviving the general wreck, is reserved for a higher destiny? Can that, within man, which reasons like his immortal Creator—which sees and acknowledges His wisdom, and approves of His designs, be mortal like the rest? Is it probable, nay, is it possible, that what can thus com-

prehend the operations of an immortal Agent, *Is not itself immortal?*

Thus has reasoned man in all ages; and his desires and his feelings, his hopes and his fears, have all conspired with his reason, to strengthen the conviction, that there is something within him which *cannot die.* That he is destined, in short, for a future state of existence, where his nature will be exalted, and his knowledge perfected; and where the GREAT DESIGN of his Creator, commenced and left imperfect here below, WILL BE COMPLETED.

BOOK III.

OF THE CHEMISTRY OF ORGANIZATION: PARTICULARLY OF THE CHEMICAL PROCESS OF DIGESTION; AND OF THE SUBSEQUENT PROCESS BY WHICH VARIOUS ALIMENTARY SUBSTANCES ARE ASSIMILATED TO, AND BECOME COMPONENT PARTS OF, A LIVING BODY.

HAVING in the foregoing pages, given a summary view of the Chemical properties of bodies not organized, and of the laws of their union; having also considered the general relations of inanimate matter and of organized beings, on the great scale in which they are offered to us by nature, together with the present position and future prospects of man; we now proceed, in the last place, to inquire more particularly into the means by which organization is accomplished; or, in other words, to give a summary view of those chemical properties, and laws of union, by which organized beings are distinguished from inorganic matters.

CHAPTER I.

OF THE NATURE AND COMPOSITION OF ORGANIZED BODIES IN GENERAL, AS COMPARED WITH INORGANIC MATTERS.

"A LIVING being considered as an object of chemical research, is a laboratory, within which a number of chemical operations are conducted; of these operations, one chief object is to produce all those phenomena, which taken collectively are denominated *Life;* while another chief object is to develope gradually the corporeal machine or Laboratory itself, from its existence in the condition of an atom, as it were, to its utmost state of perfection. From this point of utmost perfection, the whole begins to decline as gradually as it had been developed; the operations are performed in a manner less and less perfect, till at length the being ceases to live; and the elements of which it is composed, again set free, obey the general laws of inorganic nature."*

Such is the history of organic existence; nor, though the periods of developement and of decay be infinitely varied in different species, does a single individual remain for a moment stationary; but all, sooner or later, transcend their prime, and finally share the common lot of dissolution.

That peculiar principle or principles, which under some condition or other, exists in all organized beings, and by which they

* Berzelius, Traité de Chimie, tom. v. p. 1.

are distinguished from inanimate matter, has received various appellations. In the present inquiry these principles may be viewed as agents: and to discriminate them from Heat, Electricity, and other agents or inorganic matters, they may be denominated *organic agents*. In conducting our investigations into the nature of these principles or agents, our difficulty will be much lessened, by endeavouring previously to have a clear understanding of what these agents actually do. We shall, therefore, in the first place, give a short sketch,

1. *Of Organic Bodies considered as Chemical Compounds.*—In their well-marked forms no two things perhaps can be conceived to offer a stronger contrast, than the two great divisions of organic bodies—vegetables and animals. Yet these two kinds of bodies so gradually approximate, and seem even to coalesce, that it is not possible to say where the one ends and the other begins. The same remark applies to the chemical composition of vegetables and animals. Vegetable substances, in general, contain essentially no more than three elements, *Hydrogen*, *Carbon*, and *Oxygen;* while animal substances usually involve a fourth, *Azote*. Yet there are many vegetable substances, of whose composition, azote forms a considerable part; while certain animal substances are entirely wanting in that principle. It is obvious, therefore, that the mere chemical composition of a substance, at least its essentially consisting of three or four of these elements, will not enable us to determine whether it be vegetable or animal; and that, in many substances, when this point happens to be doubtful or unknown, we must have other data before we can form a conclusion. Besides these four elements, of which all organic substances are essentially compounds; other principles generally enter into their composition. These other principles are in very minute quantity, and are not so essential to the actual existence of organic substances, as the four constituent elements above named; yet, however minute the quantity, the influence of these other principles seems to be most important; they are, *Sulphur*, *Phosphorus*, *Chlorine*, *Fluorine*, *Iron*, *Potassium*, *Sodium*, *Calcium*, *Magnesium*, and probably more besides. These principles, have, by most chemists, been deemed extraneous, or foreign to organized bodies; but we shall presently show, that there is good reason to believe, that the office of such additional principles, though different from that of the constituent elements, is nevertheless most remarkable. These four elements, along with the additional principles, are, in the present state of our knowledge, alike denominated, *The Ultimate Elements* of organized bodies; but hydrogen, carbon, oxygen, and azote, may be termed, for sake of distinction, the *essential* elements; and sulphur, phosphorus, &c. the *incidental* elements of such bodies. The com-

binations of these ultimate elements with one another, according to certain laws, produce what are denominated the *Immediate*, or *Proximate Elements* of organized bodies. Of these proximate elements, *Sugar*, *Oil*, *Albumen*, &c. are familiar examples.

Perhaps it may be stated as a general law, that no substance, entering into the composition of a *living* plant or animal, is so pure as to be capable of assuming a regularly crystallized form. Instead, therefore, of being defined by straight lines and angles, almost all solid organized substances are more or less rounded, and their intimate structure is anything but crystallized. The composition of organized fluids is equally heterogeneous; and though the basis of nearly every one of such fluids be water, many of them contain a variety of other matters.

Organized bodies may be ranged under two general classes; those which though they do not crystallize, while in the living plant or animal, can yet, by various processes, be so far separated from extraneous matters, as to be obtained in a state of purity, and thus be made to assume the crystallized form; and those which cannot under any circumstances be made to crystallize. The first substance of the crystallizable class which we shall notice, is *Sugar*.

Sugar has been ascertained, and is now generally admitted, to consist of three essential elementary principles—hydrogen, oxygen, and carbon; it is besides remarkable, that the hydrogen and the oxygen in sugar are exactly in the proportion to each other, in which they form water. It has been, therefore, with great probability inferred, that these two elements are really so associated in sugar; consequently, that sugar is a compound of water and carbon; or, in the language of Chemists, is a *Hydrate* of Carbon. We cannot, however, produce artificially either sugar, or any other organic compound, by directly combining their elements; because we cannot bring the elements together, precisely in the requisite states and proportions. Still, there is no doubt, that if the elements could be so brought together, the compound thence resulting, would be the same as the natural compound. For, as hereafter we shall endeavour to show, the organic agent does not change the properties of the elements; but simply combines them in modes which we cannot imitate.

Vinegar is another well known proximate principle, which not only forms crystallized compounds readily with many other bodies; but in its most concentrated state, is itself also crystallized. Now, it is not less worthy of note than in the case of sugar, that vinegar, altogether so different from sugar in its properties, is generally considered to be precisely analogous in its composition; that is to say, vinegar is a binary compound of water and carbon; but the proportions of water and carbon are different from those that form sugar. There is however, a cha-

racteristic distinction between these two substances, inasmuch as vinegar can be formed artificially ; not indeed, any more than sugar, by directly associating its elements : but, by the process of fermentation, and by other means, this acid may be formed from sugar and from the allied substances to be presently mentioned. Yet we cannot work backwards, and by any artificial process again form sugar from vinegar ; though the organic agent seems to possess this power, as we shall have occasion to notice more particularly hereafter.

We now proceed to consider the composition of a totally different class of substances, which under no circumstances, natural or artificial, ever assume the crystallized form ; and the structure of which, in the common and strict sense of the term, may be said to be *organized*. *Starch* is a well known instance of these uncrystallizable or organized substances.

The amylaceous or starchy principle is obtained in slightly modified states, from a great variety of vegetables, but principally from the seeds of the *Cerealia*. Even by the unassisted eye, starch is seen to be composed of minute particles ; and when these particles are examined with a microscope, they are found to be granules more or less rounded, and without the least trace of crystallization. These granules are conceived to be moulded in the cellules of the texture by which they are formed ; for it would appear that their state when first secreted and deposited in the cellules is semifluid ; and that the excess of water is subsequently removed. Raspail and Dumas have shown that each of these little grains is covered with a smooth integument, not affected by water at the common temperatures ; within which integument is enclosed a substance rather more soluble. According to some chemists, this interior substance has an analogy with gum ; but probably it is only a variety of amylaceous matter. Berzelius affirms that starch when burnt, leaves about .23 per cent of residuum, consisting entirely of the phosphates. But when this residuum is abstracted and allowed for, the essential composition of starch is found to coincide very nearly with that of sugar ; that is to say, starch is composed of water and carbon, and the proportions of their combination are very nearly the same as in sugar. Here a question arises : How does it happen that substances which appear to resemble each other so closely in their composition, should yet differ so widely in their sensible properties ? This question we shall soon consider. But in the mean time, we shall make a few remarks on another principle of organized bodies, still very different, in its sensible properties, from the three of which we have spoken, but apparently of a similar constitution. This fourth principle is the *woody* fibre, or *Lignin*, as it is termed by chemists.

The woody fibre, though assuming a great variety of appearances in different plants, and including very different incidental matters; has nevertheless, in all those plants in which it has yet been examined, been found to possess very nearly the same essential composition; or to consist of equal weights of water and of carbon. Such, at least, is the composition of woods, so very different as the Box and the Willow, the Oak and the Beech; and these are the chief, if not the whole, of the woods which, we believe, have yet been analyzed. Hence, it is perhaps not unreasonable to suppose that every variety of Lignin has a similar composition. All woods, when burnt, leave a greater or less quantity of incidental mineral residuum, in the shape of ashes; the nature of which, as above observed, differs exceedingly in different sorts of wood.

The following Table presents a summary view of the composition of the four organic principles which we have considered in the preceding paragraphs. It is offered, not only as an example of the boundless subject of the Chemistry of Organization, but as an instance of the mode by which we conceive, that department of Chemistry may be best elucidated.

Substances Crystallizable.			*Substances* not *Crystallizable.*		
	Carbon.	Water.		Carbon.	Water.
Sugar, from Starch - -	36.20	63.80	Starch, Arrow-root in its ordinary state - -	36.4	63.6
from Honey	36.36	63.63	from Wheat, in its ordinary state	37.5	62.5
East India Moist - -	40.88	59.12	ditto, ditto, dried at 212° - -	42.8	57.2
Beet root and Maple - -	42.10	57.90			
English Refined - - -	41.5 to 42.5	58.5 to 57.5			
Pure Sugar Candy - -	42.85	57.15			
Acetic Acid -	47.05	52.95	- - - - - -		
- - - - - - -			Lignin, in its ordinary state of dryness	42.7	57.3
			from Willow, dried at 212°.	49.8	50.2
			from Box, do	50	50

A cursory inspection of the foregoing Table will evince to the

reader, how nearly the general composition of sugar and of starch agree together; and that the agreement extends even to their several varieties. Vinegar, or acetic acid, has not, at present, any known representative, among other organic principles; though it is not improbable that several substances exist of conformable proportions. The composition of vinegar, or acetic acid, is intermediate to that of sugar and of Lignin; while among crystallizable organic substances, there is no known compound analogous to Lignin. It may, at the same time, be remarked, that both starch and wood can, by different artificial processes, be converted either into sugar or into vinegar. We can also convert wood into a sort of starch, as we may convert sugar into vinegar; but we are unable to reverse the process, and convert vinegar into sugar, or starch into wood; though these and innumerable changes of a similar kind are easily affected by organic agency.

We proceed now to consider briefly the question we have already stated,

2. *How does it happen that substances, so nearly allied in their composition, exhibit sensible properties so entirely different?*—This question, in all its bearings, is probably beyond our powers of investigation: at least the extent of the requisite knowledge we have yet attained, must be allowed to be exceedingly inadequate. The few observations which we have to offer regarding this question may be comprised under the two following heads:—The *peculiarity of the composition* of organic substances; and the *nature of the agents* by which these substances are produced.

The *composition* of organized bodies may be viewed as of two general kinds, viz. their composition, as depending simply upon differences among the proportions of their essential elements; and their composition as depending upon differences among their incidental elements, the proportions of the essential elements being the same.* As instances of the first kind of composition, we may mention sugar and vinegar. Thus, sugar is composed of 42.85 per cent of carbon, and the rest water; while the same ingredient, carbon, in the larger proportion of 47.05 per cent, with the residue water, constitutes vinegar, a powerful acid. Why, with such similarity of composition, the sensible properties of these two substances should be so unlike, we know not; any

* Of course there is a third, and perhaps the most extensive class of bodies, in which both the essential and the incidental elements may be supposed to vary; but partly from want of data, and partly to avoid too much complication, we shall not enter upon the consideration of this class at present.

more than we know why oxygen and hydrogen, when combined, form water, or than we know any ultimate chemical fact. However wonderful, therefore the results of these slight differences of composition may, at the first view, appear; a little reflection will convince us, that in reality, they are not more wonderful than any other chemical phenomenon; and that they only form a particular variety of such phenomena. The same remarks are applicable, in part at least, to the striking differences exhibited by Sugar and Starch; the essential composition of which two substances, as we have before observed, is nearly the same; but the starch contains incidental bodies, from which the sugar is free. On the operation of these incidental bodies we shall offer a few conjectural remarks.

At the commencement of this chapter, we stated that the incidental substances existing in organized bodies have hitherto been considered as foreign; but that we could not subscribe to that notion. We may now observe, that they seem to us, to contribute chiefly towards the production of those striking differences, observed among bodies having the same essential composition; and which diversity, at first sight, appears so mysterious. How these minute quantities operate we do not precisely understand; but we can imagine them to be interposed among the constituent molecules: further, that the molecules of these incidental matters are in a state of strong self-repulsion. Such being the case, it is not unreasonable to expect that they may have the power of modifying the arrangement of the constituent molecules; and thus of altering the sensible properties of the substance produced by their combination.

We have stated our opinion that the molecules of incidental matters in organic substances are in a state of self-repulsion. This opinion is founded principally, on the equal diffusion of these incidental molecules throughout the organic substances in which they exist; and on their consequent great distance from each other, which, perhaps, can hardly be otherwise explained. If these incidental matters were detached, or merely in a state of mixture with the constituent elements, as is implied in the notion of their being foreign, they would probably retain their self-attractive powers; and instead of being equally diffused among the constituent elements, they would be collected together into a mass or crystal; an arrangement never observed. For, though crystallized bodies are found, not unfrequently, within organized substances; yet these bodies are always extraneous, and do not form any part of the living structure; of which, the molecules under our consideration do actually appear to be integrants. In further corroboration of this opinion, may be adduced the beautiful experiments of Sir John Herschel, who has shown, that an enor-

mous power, not less than 50,000 times the power of gravity, is instantaneously generated by the simple agency of common matters submitted to galvanic influence; as, for example, by the agency of mercury alloyed with a millionth part of its weight of sodium. These facts, while they place beyond all doubt, the efficacy of minute quantities of matter, in producing the most extraordinary change of the polarities of larger quantities; at the same time appear to throw great light on many natural operations. Thus the subtle matters of contagion and miasmata; various medicinal substances, whose effects are most astonishing even in the smallest doses; the still more refined and recondite matters of heat and of light, with many others, all probably act on similar principles. At least, the results of the operation of these matters cannot be explained by their mere quantity; which in the ordinary chemical acceptation of the term, is altogether incommensurate with the evident and striking changes, constantly arising in the processes of nature, from such agency.

The observations that have now been offered, are intended to apply to all those elementary substances, entering into the composition of a living organized being. For, no one element, when thus assimilated, appears to be in its natural state; or to be capable of exerting precisely those powers which it is known to exert, when acting in virtue of its original inorganic properties. In short, we may thus recapitulate what has been said: besides the essential molecules constituting the ground-work of a living organized being, and which probably exert on each other, to a certain extent, the ordinary chemical influences of matter; it would seem that there are, at the same time, diffused throughout the whole living mass, in exceedingly minute proportion, various other matters, the molecules of which appear to be in a high state of self-repulsion. By these incidental matters, it would further seem, that the ordinary chemical properties of the essential elements of the organized living structure are variously modified; in particular, that, the essential elements are hindered from assuming a regularly crystallized form. Moreover, these incidental matters entering into the composition of a living body, apparently furnish to the organic agent new powers utterly beyond our comprehension; which powers the organic agent has been endowed with the ability to control, and direct, in any manner that, from the exigencies of the living organized being, may become requisite.*

The intimate nature of the *organic agent* or *agents*, or by

* In addition to what is stated in the text, we may remind the reader of what we have elsewhere alluded to, viz.: that the organic agents have

whatever other name we may choose to designate the peculiar energies which exist in plants and in animals, and by which they are distinguished from inanimate matter, is now, and probably will ever remain, altogether unknown to us. But though we be thus ignorant of what these agents are; we can not only comprehend with tolerable certainty, what they *are not;* but we can also in some degree ascertain, what they are capable or incapable of effecting. As it is of the utmost consequence to obtain just views on these points, we shall consider them somewhat in detail.

When we were treating of inorganic elements and agencies, and of the laws which they appear mutually to obey, we found, that though their nature be obscure, and the investigation of them very difficult; we were nevertheless enabled to adduce some, not altogether unplausible, conjectures on the modes, in which the elements combine, to form regular crystals and the other conditions of inanimate matter. Now with this insight into the nature of inorganic operations, and with all the additional knowledge of every kind that we can command, let us attentively survey the most simple plant or animal; let us observe the actions, the changes, the modifications of form and properties it continually exhibits; and then let us seriously ask ourselves, whether everything that we know, will enable us to make, even an approach, toward an explanation of what we see. It is indeed true, that the plant or animal we examine is composed of charcoal and water, and of other ingredients with which we are equally familiar; that it is liable to be affected by Heat, Light, Electricity, and by other inorganic agents. But it is perfectly ascertained that these elements and agents, out of an organized body, *and left entirely to themselves*, never would or could unite, either in virtue of their own properties, or from accident, so as to form any plant or animal however insignificant. Are we not then compelled to infer, that within a plant or animal, there exists a principle or agent superior to those whose operations we witness in the inorganic world; and which agent moreover possesses, under certain restraints, the power of controlling and directing the operations of these inferior agents? That this is a natural and a just inference, no one who calmly views all the circumstances will ever deny; and if the existence of one such agent be admitted, the admission of the existence of others can scarcely be withheld; for the existence of one only, is quite inadequate to explain the

probably the power, within certain limits, of separating the molecules of bodies, considered at present as elementary, into more refined forms of matter (submolecules?).

infinite diversity among plants and animals. Thus, in the words of the excellent Paley, "there may be many such agents, and many ranks of them:" in other words, there may be an ascending gradation of these agents, from that of the comparatively simple plant, onward to that of the most complicated animal.

Such being the suggestions concerning organic agency that arise from a general survey of organic operations; let us, with reference to the further bearing and tendency of these suggestions, inquire a little more minutely into the powers and modes of operation of organic agents.

3. *Of the modes of Operation of Organic Agents.*—In the first place, with regard to what *cannot* be effected by organic agency, we may observe, that no organic agent has the power either of *creating* material elements, or of *changing* one such element into another. By element, it may be right to premise, is here meant, a principle that is not made up of others; and which, consequently, possesses an absolute and independent existence. Whether one, or more, such elements exist, it is not now our object to inquire. The astonishing discoveries of modern chemistry have shown, that many of those substances, formerly considered as elements, are, in fact, compounds; and as the science of chemistry is still progressive, it is probable that, with the enlargement of its boundaries, there will be a still further diminution of the number of those substances which are, as yet, held to be simple. Admitting, however, for the sake of argument, that elementary principles do exist, of such immutable character as has been supposed; from the nature of organic beings, at least of all animals, it is impossible to conceive that they possess the power either of creating or of altering these elementary principles. For no organized being has an independent existence, but all animals derive their support from previous organization, which might be otherwise, did they possess a creating power; nor can they be nourished by all substances indiscriminately, as they ought to be, were they possessed of a transmuting power. Yet, while it is thus denied that organized beings possess the power, either, to create or to change, in the strict acceptation of these terms; it has been admitted to be exceedingly probable, that the organic agent is, within certain limits, qualified to compose and decompose many substances which are now viewed as elements; and that the organic agent does thus apparently form and transmute these imagined elements. But to enter further, in this place, on the elucidation of these obscurities would be foreign to our present purpose.

The organic agent has not the power of combining elements in such a manner, that the properties of the resulting compound shall *differ* from those of a compound, formed from the same

elements similarly combined by any other agent. The Deity has chosen to prescribe limits to his power, and to establish certain laws, to which He at all times rigidly adheres ; and, again adopting the language of Paley, " when a particular purpose is to be effected, it is not by making a new law, nor by the suspension of the old ones, nor by making them wind, and bend, and yield to the occasion ; but it is by the interposition of an apparatus corresponding with those laws, and suited to the exigency which results from them, that the purpose is at length attained." In the instance before us, the attainment of the particular purpose of organic life is effected, not by any departure from the great scheme, but by new and different combinations. To suppose, therefore, that the organic agent can, for example, combine oxygen and hydrogen, in exactly the same proportion, and in the same manner, in which they are combined, when they exist as water ; and, from these elements so combined, can yet produce something different from water, is contrary to all reason, and would be, in truth, to accuse the Deity of subverting, and of acting in opposition to, his own laws. We have dwelt the more strongly on these points, because among physiologists a vague notion seems to have prevailed, that organic agents have the power, not only of changing the inherent and peculiar properties of bodies ; but likewise, of causing the results of their combination to be altogether different from those that are produced, under exactly similar circumstances, by inorganic agency. If however the arguments we have advanced be well founded, this notion must be erroneous ; and its erroneous character will be rendered still more evident, by the observations, we shall, in the second place, offer, regarding the principles on which the operations within living organized bodies are really conducted.

The means by which organic agents accomplish the purpose for which they are designed, may be naturally divided into two kinds ; those which are dependent on *peculiarity of composition and of structure ;* and those by which *this peculiarity of composition and of structure is produced.*

Inquiry into the *first* of these means of action has already been in great degree anticipated. A brief recital, therefore, is all that is here necessary. We have seen that organized substances are composed of the same elements, which exist abundantly throughout the world in the inorganized state ; moreover that these elements are subject to all the influences and agencies of inorganic nature. We have seen that organic agents are enabled to form certain proximate principles, by variously combining their elements ; which proximate principles, even when in the condition of crystals, it is not possible to imitate artificially. We have, at the same time, seen that these proximate principles,

though they may have a natural tendency to crystallize, are, as they usually exist in living bodies, prevented from undergoing that process, by the diffusion of minute quantities of other elements throughout their mass ; the molecules of which are in some unknown state of activity ; such perhaps as cannot naturally exist in the universe, except when conjoined with organization. Finally, we have inferred, that the differences and peculiarities of these minute additional matters, are probably adequate for explaining the differences and peculiarities, of the sensible and chemical properties of the substances that are formed by organization. Having thus pointed out the general differences of composition existing among organized bodies; it remains to state, that such differences of composition almost invariably indicate differences of structure. For though similarity of composition does not necessarily imply similarity of structure ; yet similarity of structure perhaps, without exception, indicates similarity, or, at least, analogy of composition ; and, consequently, *similarity of action*. Thus the woody fibre of plants is always formed of the principle termed *Lignin*, and never of resin, or of albumen. The relation of structure to chemical composition is not less striking in the muscular fibres of animals, and indeed in all organic compounds of a definite character ; the essential composition of such substances, though exhibiting endless minor diversities, being nevertheless, in all instances, precisely the same.

The means by which that *peculiarity of composition and of structure is produced*, which is so remarkable in all organic substances, like the results themselves, are quite peculiar ; and bear little or no resemblance to any artificial process of chemistry. For example, we have not, in artificial chemistry, any control over individual molecules ; but are obliged to direct our operations on a mass, formed of a large collection of molecules. The organic agent, on the contrary, having an apparatus of extreme minuteness, is enabled to operate on each individual molecule separately ; and thus, according to the object designed, to exclude some molecules, and to bring others into contact. In these processes, it may be conceived, that the molecules thus appropriately brought together, and, at the same time, guarded from extraneous influence, by the organic agent, are in virtue of their own proper affinities, sufficiently disposed to unite, without requiring that any new properties should be communicated to them. Hence the organic agent, in its simplest state, may be viewed as a power which so controls certain inorganic matters, as to form them into an apparatus, by which it arranges and organizes other matters, and thus effects its ulterior purposes. Where the operations of this simple organic agent terminate, those of another and more effective organic agent may be supposed to

begin ; which, by carrying the general process of organization a step further, adapts the organized material for the operations of a third and yet higher agent. Thus, each new agent may be supposed to possess more or less control over all those below itself, and to have the power of appropriating their services ; till at length, at the top of the scale, we reach the perfection of organized existence. The excellent Paley sanctions this view of organic operations, and continues in the following words : " We do not advance this as a doctrine either of philosophy or of religion ; but we say that the subject may safely be represented under this view ; because the Deity, acting himself by general laws, will have the same consequences upon our reasoning, as if he had prescribed these laws to another." .

This view of the successive creation of organic agents, which harmonizes not only with the phenomena of Geology, but with the differences which are observable among plants and animals, and with the developement of the more perfect species ; is directly opposed to the notion of spontaneous developement maintained by some distinguished French philosophers ; as well as to the opinion that life is the *result* of organization. Thus we consider it impossible that by any accidental concurrence of circumstances, a dog can, in the progress of time, be gradually converted into an ape, or an ape into a man ; and moreover, we not only think such an hypothesis directly at variance with the whole tenor of the laws of nature, but quite absurd. The laws of nature, as we have shown, are in all cases most rigidly adhered to by the Deity. These laws, therefore, are unalterably stable, within the limits that have been assigned to them. Now, from what we know of the laws of nature, or of the properties of the elements of matter, or of the agents by which they are moved, it is, as we have already stated, impossible to conceive that carbon, water, and electricity, of their own accord, and from any inherent influence, can so unite as to form the humblest plant or animal ; much less, so as to secure its perpetual existence by reproduction. For similar reasons it is equally impossible to conceive, that there can ever be such a spontaneous arrangement or combination of *inferior* organic agents, as to form a *superior* agent. Whenever, therefore, a new and specific agent is required, a new and specific act of creation must be performed by the Great Architect of the universe. Nearly similar remarks apply to the opinion that the living principle is the *result* of organization. The living principle is *not* the *result* of organization, but the *cause* of organization. In accounting for the phenomena of life, it is absolutely necessary to assume the existence of some agency different from, and superior to, that which operates among inorganic matters. Now since, as we have seen, no inferior agencies can be supposed so to combine as to form a

superior agency; does it not accord better with our reason, as well as with our experience, to assume at once a new creation of the higher principle?

The first circumstance that arrests our attention, with reference to the preceding remarks, is the wonderful adaptation of the elements and the agents of organic nature to each other. For example, had not carbon, and azote, and water, been formed with the properties which they now possess, organic agents, as we know them, would have existed in vain; and without organic agents, the properties of these elements would equally have been useless. And how truly wonderful, and utterly beyond our comprehension, are the properties and adaptations displayed in the processes of organization! To enable ourselves to form some conception of these processes, by bringing to a level with our understanding, those things which they accomplish; let us propose to ourselves the question,—What ought to be the inherent properties and the constitution of an elementary principle, which should not only be capable of being formed into the hardest and the softest bodies in nature; but which should also be capable of entering as an essential ingredient into substances so very unlike, as sugar, vinegar, wood, oil, albumen, and many others, in all their countless forms and varieties? Do we not feel all our fancied knowledge annihilated by such a question? Nay what is more, even when the question is answered for us; and when, with the utmost care, and to the furthest extent of our ability, we have studied all the chemical properties of Carbon—the substance by which the conditions of the question are fulfilled; how totally unable are we to explain these properties, or even to trace them through their simplest modifications? Why, for instance, is the diamond capable of assuming the form of charcoal; or why is charcoal capable of assuming the form of the diamond? And how are these properties modified, and altered, in all the numerous states of combination into which we know carbon enters? On what property or quality, not possessed by other elements, do all those astonishing capabilities of change depend, which are inherent in this element carbon? And why has carbon been chosen for forming organized beings, in preference to silex, or iron, or any other element?* To us all

* Since there is nothing peculiar in the elements of which organized beings are composed, and no reason can be assigned why carbon and other elements have been chosen for their formation, we are compelled to ascribe the choice of these materials to the will of the Great Creator. But as He never acts without a purpose, we cannot doubt that these elements have been selected for some specific design; which design has probably been, that the fabric of the beings dwelling on this earth, might be adapted to its general position in the Solar system. When we consider that the same heat, and the same light diffused by the same central sun; that

these things are absolutely unknown; but what a conception do they give, of that inscrutable agency by which the elements are governed; of the powers of that Almighty Mind who is conversant with them all—by whom they were first designed, and by whom they have all been created! How infinitely must His knowledge surpass whatever we can imagine: how far is His power beyond our utmost calculation!

On the other hand, if the properties of the elements of matter be wonderful, yet more wonderful are those agents within organized bodies, by which they are directed. With the intimate nature indeed of these agents we have not the remotest acquaintance, nor, probably, ever shall have. But, as has been already stated, we can trace, to a certain extent, the laws of action which these agents obey; we observe their unvarying adaptation to the properties of carbon, azote, and water, on which they chiefly act; their power, within certain limits, of guiding and controlling inorganic agents; and more than all, that mysterious periodic developement and decay, which every organized being undergoes. These facts which continually present themselves to our notice, are totally inexplicable according to those laws by which inorganic bodies are governed; and are referrible only, to an order of laws, which the Great Author of Nature has not chosen to reveal.

Lastly, we cannot close this chapter, without pointing out to the reader a very remarkable contrast, in the two classes of objects which have engaged our attention. The number and diversity of organic agents appear to be endless; in the creation, therefore, of these agents, the Great Author of Nature has chosen to manifest his attribute of infinity. But in the creation of the material elements which compose the frame of organized beings, He has adopted a plan directly opposite. Instead of different principles; the same carbon, the same azote, the same water, enter into every living being, from the lowest plant upward to man. Amidst the wonders of creation, it is perhaps difficult to say what is most wonderful; but we have often thought, that the Deity has displayed a greater stretch of power, in accommodating to such an extraordinary variety of changes, a material so unpromising and so refrac-

the whole system obeys the same laws; and that the different planets influence, and are influenced by each other; we are warranted in believing that the planets are essentially composed of the same elementary principles. But admitting that the heat and light of the sun are distributed according to the laws which they seem universally to obey; the heat in Mercury, close to the sun, and the cold in Saturn, at the other extreme, must be alike so intense, that organized beings, such as inhabit this earth, could not exist for a moment. In the different planets, therefore, may not the living principle be attached to different elements, more or less fixed or volatile, as the distance of the planet from the sun may require?

tory as charcoal, and in finally uniting it with the human mind; than was requisite for the creation of the human mind itself. To Him, however, all things are alike easy of accomplishment; and He, doubtless, has willed these and other proofs of His omnipotence, in order to convince us of this truth,—that the Creator of the mind, could alone have created the matter with which the mind is associated!

CHAPTER II.

OF THE MODES OF NUTRITION; COMPREHENDING A SKETCH OF THE ALIMENTARY APPARATUS; AND OF ALIMENTARY SUBSTANCES IN PLANTS, AND IN ANIMALS.

THE subsistence of all organized beings is derived from sources external to themselves. Their means of subsistence, however, as well as the modes in which the aliments are applied, exhibit an almost endless variety. As might be expected, the widest differences, both in the nature of the alimentary substances, and in the manner of their introduction, are between plants and animals. We shall, therefore, consider the subject of nutrition under these two heads.

SECTION I.

Of the Modes of the Nutrition of Plants; and of the Nature of those Matters by which their Nutrition is effected.

A MINUTE investigation of the anatomy and the physiology of plants would be quite foreign to the object of this treatise. At the same time, it is necessary that the reader should have some insight into these departments of knowledge, in order that he may be enabled to understand the collateral researches which it is our duty to illustrate.

"If we reflect upon the phenomena of vegetation," says Professor Lindley, "our minds can scarcely fail to be deeply impressed with admiration at the perfect simplicity, and, at the same time, faultless skill, with which all the machinery is contrived, upon which vegetable life depends. A few forms of tissue interwoven horizontally and perpendicularly constitute a *stem;* the developement, by the first shoot that the seed produces, of buds which grow upon the same plan as the first shoot itself, and a constant succession of the same phenomenon, causes an

increase in the length and breadth of the plant; an expansion of the bark into a *leaf*, within which ramify veins proceeding from the seat of nutritive matter in the new shoot, the provision of air passages in its substance, and of evaporating pores on its surface, enables the crude fluid sent from the roots to be elaborated and digested until it becomes the *peculiar secretion* of the species: the contraction of the branch and its leaves forms a *flower;* the disintegration of the internal tissue of a *petal* forms an *anther;* the folding inwards of a leaf is sufficient to constitute a *pistillum;* and finally, the gorging of the pistillum with fluid which it cannot part with, causes the production of a *fruit*."*

The "crude fluid sent up from the roots" of plants, or their *sap*, as it is termed, is found to consist of water, mucilage, and sugar, with some minute portions of other matters, generally saline. Though, under certain circumstances, moisture be absorbed by the leaves of all plants, yet there is no doubt that a great part of their nourishment enters by their roots; not, however, by the whole root indiscriminately: the nourishment of plants is taken up chiefly by the minute fibrous parts termed *spongioles*. Hence, these minute fibrous parts are of the utmost importance in the vegetable economy, and ought to be carefully preserved in transplantation, otherwise the plant will certainly perish. In some instances, roots appear to be intended to act as reservoirs of nourishment for the support of the plants of the succeeding year, on their first developement. There are such roots in the *Orchis* and *Dahlia* tribes, and in others. Of late it seems to have been satisfactorily established, that the roots of all plants, besides imbibing nourishment, perform also an excretory office; and that in the soil in which plants grow, there are deposited by the roots, certain matters of an excrementitious nature, injurious to the plants from which they have been separated; and which therefore, cannot be absorbed again, till they have undergone decomposition. Such excreted matters have been adduced as the reason, why a soil becomes so much deteriorated by any one species of plant having long grown in it, that it will not support other individuals of the same species: whence the necessity of a rotation of crops.

The principal ingredient in the sap of plants, as already observed, is water. The quantity of sap in some plants, is almost incredible; and not less so, is the force with which, on the approach of warm weather in our climates, and at the commencement of the rainy season within the tropics, that sap is determined upwards. The general composition of the sap varies considerably in different parts of the same plant. For instance, sap taken from

* Introduction to Botany, p. 216.

the roots is little more than water; while the quantity of saccharine and other matters contained in the sap, increases in its progress along the stem to the higher parts of the plant. When the sap begins to rise, the leaves at the same time begin to be developed. From the leaves principally the watery portions of the sap are evaporated; and the evaporation is copious and unceasing. The more solid matters thus remain dissolved in a less proportion of water; and after undergoing further changes, as is supposed, in the leaves chiefly, these matters are returned, along with the remaining water, to be deposited in other parts of the plant, for its future uses. It seems now to be generally admitted, that one part of the food of plants is the matter extracted from the soil; and that this matter is taken up with the watery portion of the sap above mentioned. It seems also to be admitted, that carbonic acid gas is in some way indispensable to vegetation; "for it has been ascertained, that feed plants as you will, they will neither grow nor live, whether you offer them oxygen, hydrogen, azote, or any other gaseous or fluid principle, unless carbonic acid is present." Like the other nutritious matters, this carbonic acid is partly taken up by the roots; but under certain circumstances, it is also separated from the air, and absorbed by the leaves. The circumstances under which this absorption, or rather decomposition, of carbonic acid, by the leaves takes place, are most curious and important. They are understood to be as follows:

During the day, and particularly during sunshine, the leaves of plants have the power of abstracting the carbonic acid from the atmosphere. The carbon of the acid, and perhaps also a little of its oxygen combine with the plant; while the greater part of the oxygen remains, and is diffused through the atmosphere in a gaseous state. During the night, on the contrary, or in the shade, plants, in general, convert a portion of the oxygen of the atmosphere into carbonic acid; but the quantity thus converted, is less than that separated from the carbonic acid which they decompose, under the influence of the solar light. At the same time with this formation of carbonic acid by plants during the night, they are said also to absorb from the atmosphere a certain portion of oxygen; to replace that which had been given off, during exposure to sunshine, on the preceding day. Plants absorb carbon as long as they are exposed to the light; during the season, therefore, when the day is long and the night is short, plants give off much less carbon than they absorb. This excess of the absorption of carbon, is probably one reason why in the Polar latitudes, the progress of vegetation is so rapid. By a beautiful provision of nature, in the course of the short summer of a few weeks, but of unvarying light, plants, in these latitudes, go through all the changes which in hotter climates require many months.

These phenomena of gaseous absorption and secretion in the leaves of plants, seem to be produced by a portion of the leaf peculiarly organized, and situated immediately under its external covering or epidermis. Professor Burnet has lately explained these phenomena, by referring them to the respiration and digestion of plants. The process of respiration in plants, is supposed to be continual; and to be accompanied, as in animals, by the formation and emission of carbonic acid gas. While digestion, which consists in the decomposition of carbonic acid gas, takes place only during the exposure of plants to the influence of the light—the carbon of the carbonic acid being separated from the oxygen, and absorbed. Hence a plant exposed to sunshine purifies the air, by digesting the carbonic acid, the carbon of which it appropriates; while it sets the oxygen free. In the dark, on the contrary, digestion ceases, but respiration continues; and carbonic acid gas is thus accumulated in the surrounding atmosphere.

With respect to the "peculiar principles of plants," these are as numerous as the individual plants themselves; so that to attempt any detailed account of them here, would be quite impracticable. Generally speaking, the peculiar principles found in plants may be divided into three great classes:—those vegetable principles in which hydrogen and oxygen are combined in the proportions that form water; as in the division of *saccharine* bodies, described in a former chapter:—those principles in which hydrogen, or rather carbon and hydrogen, predominate; which generally have more or less of an *oily* character;—and those principles in which oxygen predominates; which have usually an *acid* character. Besides these three great classes of vegetable principles, there are some that contain azote, and perhaps other elements; many of which principles also exhibit weak alkaline powers: such are the peculiar principles of Opium and other Narcotics; also of Cinchona; and a variety of others, chiefly employed as Medicinal agents.

Section II.

Of the Modes of Nutrition in Animals; and of the Alimentary Substances by which they are nourished.

To beings, like animals, endowed with locomotive powers, the absorption of their nourishment from without, would have been exceedingly inconvenient. Animals have, therefore, been furnished with an additional receptacle and apparatus subservient to nutrition, into which, as inclination or circumstances may prompt

them, their food is conveyed at intervals ; and from which, after having undergone certain changes, the food is absorbed and distributed over their system, as the exigencies of that system may require. Hence the distinction between plants and animals ;—plants absorb their nourishment by *external*, animals by *internal*, roots or *spongioles*. We need scarcely remark, that the stomach and alimentary canal, with their appendages, are the internal apparatus to which we allude ; and that this internal apparatus constitutes a marked difference between plants and animals.

1. *Of the Organs of Digestion in Animals.*—Among the different tribes of animals, there is an almost endless diversity in the formation of the alimentary organs ; and as these organs vary, not only in their own formation, but also with respect to the auxiliary apparatus, and appendages of every kind, connected with them ; any detailed account of the alimentary system would at present be quite uncalled for. In general, the alimentary canal of the higher classes of animals, consists of a tube of greater or less elongation ; expanded in some parts of its length ; terminated at one extremity by a mouth, into which the food is received ; and at the other, by a provision for the removal of excrementitious matters. In some of the less perfect animals, the alimentary canal has only one aperture ; in these animals, of course, instead of a canal, there is a kind of sac. In a very few other animals, the alimentary cavity has numerous apertures. In all instances, however, and whatever may be the nature of the alimentary matters, these matters, after having been retained for some time in the organs appropriated to nutrition, are reduced, more or less, to a fluid state—are DIGESTED, in the common sense of the term, and are converted into what is denominated *chyme*. The more nutritious parts of the fluid chyme, or the *chyle* as they are termed, are then absorbed, and distributed through the system for the reparation of the animal ; while the insoluble and other matters, are separated as excrementitious.

We have already alluded to the endless diversity observable in the form and arrangements of the alimentary canal in the different kinds of animals. A few of the most remarkable of these diversities among the more perfect animals will be noticed, in the outline we are now to give of the alimentary canal as existing in the human body.

Of the Mouth and its Appendages.—"In no apparatus put together by art," says Paley, "do I know such multifarious uses so aptly contrived as in the natural organization of the human mouth." "In this small cavity we have teeth of different shape, —first for cutting, secondly for grinding ; muscles most artificially disposed for carrying on the compound motion of the lower jaw, half lateral and half vertical, by which the mill is worked ; foun-

tains of saliva springing up in different parts of the cavity for the moistening of the food, while the mastication is going on ; glands to feed the fountains ; a muscular construction of a very peculiar kind in the back part of the cavity, for the guiding of the prepared aliment into its passage towards the stomach, and in many cases for carrying it along that passage." "In the mean time, and within the same cavity, is going on another business altogether different from what is here described—that of respiration and of speech. In addition, therefore, to all that has been mentioned, we have a passage opened from this cavity to the lungs, for the admission of air, exclusively of every other substance ; we have muscles, some in the larynx, and without number in the tongue, for the purpose of modulating that air in its passage, with a variety, a compass, and a precision of which no other musical instrument is capable. And lastly, we have a specific contrivance for dividing the pneumatic part from the mechanical, and for preventing one set of actions interfering with the other." "The mouth, with all these intentions to serve, is a single cavity ; is one machine, with its parts neither crowded nor confined, and each unembarrassed by the rest."* Such is Paley's graphic description of the human mouth and its appendages: we have quoted it at length, that it may serve as a text for illustration.

Man has been observed to differ more from other animals in the form of his *lower jaw*, than in the form of any other bone of his body. This difference consists chiefly in the prominence of the chin ; that peculiar characteristic of the human countenance, which distinguishes more or less every race of mankind, and is found in no other animal whatever. There is likewise a striking difference, among the various tribes of animals, in the mode of articulation of the lower jaw ; which in all cases is singularly adapted to the nature of the food of the animal. Thus, in the carnivorous tribes, the articulation is so arranged that the jaw can move only up and down ; and is almost entirely incapable of that lateral movement, which is essential to genuine mastication. Hence such animals cut and tear their food, and swallow it in large pieces. But those animals that live on vegetables, in addition to the vertical motion of their lower jaw, have the power of moving it backwards forwards, or to either side, so as to produce a grinding effect, admirably fitted for triturating the vegetable matters on which they subsist.

The *teeth* next claim our attention, as being not less suited to the habits of the animal, than in the form of the jaw in which they are set. Teeth are divided by naturalists into three orders : —The *Incisores*, or *cutting teeth*, placed in the front part of the mouth; the *Cuspidati*, *canine*, or *corner teeth*, usually placed

* Natural Theology, chap. ix.

near the angles of the jaw; the *Molares*, *grinding*, or *lateral* teeth, which always occupy the sides and back part of the jaw. In man, and in those animals which most nearly resemble him in their structure, teeth exist of all the above varieties of form. But many species want one or other of these varieties; while the teeth they possess, are of a form and size very unlike the same teeth in man. Thus, in animals which live chiefly on the harder vegetable substances, and which, from their peculiar mode of feeding, have been termed *gnawing* animals, the *incisor* teeth are the most remarkably developed; as these teeth are the best adapted, and indeed are the most necessary, to their habits. In *carnivorous* animals, on the other hand, the *canine* teeth are of chief importance; as enabling these animals to seize and hold their prey: in such animals, accordingly, the canine teeth are the most perfectly formed. Lastly, in the animals that feed on grass, and other *herbaceous* substances, and whose aliments require long and complete mastication, the *Molares*, or grinding teeth, attain the greatest enlargement; and in many of these animals the incisor and the canine teeth are entirely wanting. Besides the adaptation of the form, the enamel or harder cutting portion of the teeth, is distributed over and throughout their texture, according to their intended uses, in a manner that is truly extraordinary. The description however of the arrangement of the enamel, as well indeed as a minute account of the teeth themselves, belong to the physiologist, on whose province we shall not further intrude. But it is impossible to take even the most superficial view of the teeth of animals, without being struck with the admirable design and fitness they display, throughout their whole fabrication.

The next auxiliary appendages of the mouth are the *glands* that secrete the saliva; in which we observe the same beautiful arrangement as in the form and structure of the teeth. In man, though the apparatus for the secretion of the saliva, is by no means of large size, yet the quantity of fluid which the salivary glands are capable of secreting, and do secrete during mastication, is very considerable; often amounting, it is said, to half a pint or more. This fluid, in its perfectly healthy state, is neither acid nor alkaline, or alkaline only in a slight degree; but occasionally it assumes an acid character. Besides the great utility of the saliva in moistening the food, we cannot doubt that it assists, and is even necessary to the full completion of the succeeding digestive process. By a beautiful arrangement, those animals that do not masticate their food, as the carnivorous tribes, have very small salivary glands; while in animals whose food requires long mastication, as in ruminating animals—the cow and the sheep, for example, the salivary glands are very large.

The passage by which the masticated food is conveyed from the mouth to the stomach is termed the *œsophagus*. Like the

whole frame, the œsophagus is admirably adapted for its office; and in different animals, varies in size and structure, according to their habits. These differences, however, scarcely concern us at present, and we pass on to that important organ—the Stomach.

The human *stomach* is a membranous bag, of a shape rather difficult to be described, so as to convey a clear notion of it to the reader. If we imagine two cones united at their bases, and the figure thus produced to be bent into a semicircular form, some idea may be obtained of the outline of the stomach in the human species. In respect to its size, the human stomach varies: but in the adult, its capacity is usually such as to contain about two or three pints. The stomach is situated immediately under the diaphragm; but the precise place of the organ differs somewhat with its state of repletion. The general position of the stomach is transverse, or horizontal, supposing the body to be upright; the left orifice, or *cardia*, which communicates with the œsophagus, being somewhat higher than the right orifice, the *pylorus*, through which the food is transmitted to the further portion of the alimentary canal. The upper space between the two orifices is usually termed the small curvature; the lower space, the great curvature, of the stomach. Numerous glands occupy the internal surface of the stomach, particularly near its pyloric orifice. By these glands a fluid is secreted of the highest importance in the digestive functions, on the nature of which we shall enlarge hereafter.

Such is the stomach of man; but the form and the magnitude of this organ vary almost infinitely in different animals, according to the nature of their food, and other circumstances. We can, at present, notice only two or three of the most remarkable diversities. In most carnivorous animals, the stomach bears a resemblance to that of man. There is also a resemblance, at least externally, in certain herbivorous animals; as in the horse, the rabbit, and others. The internal arrangements, however, are different; thus, in the animals above mentioned, the left or cardiac half of the stomach is lined with cuticle; while the other half, towards the pylorus, has the usual villous and secreting surface. Hence, these two portions of the stomach perform very different offices, and generally contain food in very different states of reduction. The most complicated and artificial arrangement, however, both with respect to the structure of the parts, and the lining membranes, is found in the well-known four stomachs of the animals that ruminate and have divided hoofs; as the cow and the sheep. We shall endeavour to give a general description of these four stomachs. The first stomach is denominated the *Paunch*, and in the adult animal is by far the largest. The second stomach follows, and may be regarded as a globular appendage to the paunch;

from which it is distinguished, principally, by the regular and beautiful distribution of its internal membrane into polygonal cells. The third stomach is the smallest of the four, and is the most remarkable in its structure: its capacity is much diminished by numerous and broad duplicatures of its internal membrane, which are placed lengthwise, and vary in breadth in a regular order. The fourth stomach is next in size to the paunch, and is lined with a villous membrane approaching to that of the human stomach, which this fourth stomach may be supposed to represent; the three preceding stomachs having been evidently intended to prepare the refractory food of the animal for the true digestive process, which it undergoes in this last stomach. Every one is acquainted with the fact that animals furnished with the gastric arrangements above described, *ruminate;* that is to say, have the faculty of masticating a second time, and at their leisure, that food which had been hastily swallowed, and deposited in their first stomach. The contrivance by which rumination is effected is very beautiful; and is connected with the peculiar arrangement already mentioned of the four stomachs, with respect to the œsophagus: but, as it would not be easy in a few words, to give more than a general outline; we must refer the reader to anatomical works, for a more particular description of the stomachs of ruminating animals. The only other modification of the stomach which we shall notice, is that which exists in some birds; as for example, in the common fowl. The common domestic fowl, as well as many similar birds, has a sort of preliminary stomach, termed the *crop*, formed by an expansion of the œsophagus. In the crop, the hard seeds, and other compact substances which birds devour, are macerated and softened, and perhaps undergo further changes, before they enter the proper stomach, to be next considered. The proper stomach, or *gizzard*, of birds, is a hollow muscle of great strength, lined with a firm and thick epidermis, disposed in rugæ, and admirably adapted for triturating the hard matters that constitute their food. The small stones which these birds constantly swallow seem also to promote this trituration.

We have given the above short sketch of the structure of the stomachs of animals, not only that we might impart to the general reader a faint conception of the extraordinary design manifested in that structure; but to enable us to show the object of diversity of structure, when we come to speak of the function of digestion a little more in detail.

After the stomach we proceed to the consideration of the *Intestinal Canal.* In man, and in the more perfect animals, this canal assumes two well marked forms, usually termed, from their relative size, the small and the large intestines. In most animals

resembling man, the small intestines are the longest, and their internal surface is villous. The coats of the large intestines are thicker, and the membrane with which they are lined is very rarely villous. The first portion of the small intestines, from its supposed length termed the *duodenum*, or twelve-inch intestine, begins from the pyloric orifice of the stomach; and, in many animals has a course not easy to be described, so as to be intelligible to the general reader. The duodenum terminates in the second portion of the small intestines, called the *jejunum*, from its being usually empty. The duodenum differs from the stomach and other parts of the canal, in being secured in its position by various attachments; while the stomach and other parts of the canal, are comparatively loose and floating. This fixedness appears to serve many wise purposes, on which we cannot dwell here; but one purpose probably is, to ensure the easy and regular passage of the bile and the pancreatic fluids into this part of the canal. As the organs producing these important fluids are fixed, the conducting tubes necessarily require also to be connected with a fixed organ; otherwise the passage of the fluids from the secreting organs to the intestine, would be constantly liable to interruption. The duodenum is very highly organized, and its functions are probably not less important than even those of the stomach. The remainder of the small intestines is divided into the *jejunum* already mentioned, and the *ilium;* but the precise place where one ends, and the other begins, is scarcely definable; nor are the differences of structure between the two so obvious, as to require to be noticed in this place.

The large intestines exceed the small intestines in diameter, but are considerably shorter: their form and structure are also different. The first division of this portion of the alimentary canal is termed the *cæcum;* and, in man at least, may be considered as little more than the head or commencement of the next division of the large intestines, termed the *colon*. The colon is of much greater diameter than any other part of the intestinal canal, and constitutes almost the entire length of the large intestines. The colon begins low down on the right side of the abdomen, then ascending to the level of the stomach, passes across to the left side, immediately below that organ. On the left side, the colon descends again, and at the same time forms what is called the *sigmoid* flexure. The colon and the alimentary canal at length terminate in what is named the *rectum*. The texture of the colon is much thicker than that of any other portion of the canal. Its organization also is peculiar; and, like the whole arrangement, wonderfully adapted for the purposes which this portion of the canal is supposed to serve in the animal economy.

Such is the short account of the alimentary canal in man. We

shall now state some of the more remarkable diversities that are observed in the lower animals.

One of the most striking circumstances relative to the alimentary canal in animals, is its various lengths in the different classes. In man, and other omnivorous animals, the proportion is intermediate between that of carnivorous animals on the one hand, and herbivorous animals on the other. In man, the whole length of the canal is about six or seven times that of the body; while in carnivorous animals it is only from about three to five times that length; and in graminivorous animals, as in the sheep, the length of the canal is twenty-seven times that of the body. In other herbivorous animals, the length of the canal varies from twelve to sixteen times that of the body. In most birds the alimentary canal is much shorter than in quadrupeds; the length in general, being between twice and five times that of their bodies: while in many reptiles and fish, the length of the canal scarcely exceeds that of the body: in some fish it is even less; as for example, in the shark. There are animals that feed on vegetables, the length of whose alimentary canal is not so great, as in the instance above stated; the deficiency in length being apparently made up in breadth. Thus, in the horse, the stomach is simple, and not much developed, when compared with the size of the animal; nor are the intestines very remarkable for their length; but the cœcum and the large intestines are enormously expanded in diameter. The cœcum of the horse seems to perform many of the offices of a second stomach, and is of fully equal capacity. There are in animals, many other beautiful arrangements of the digestive organs, which we shall pass without further notice; as our desire is to inform the reader of the general connection and adaptation, which exists between the structure of animals, and the food on which they live. It remains to conclude this outline of the digestive organs, with a few remarks on those almost invariable accompaniments of the alimentary canal,—the *liver*, the *pancreas*, and the *spleen*.

The liver is the largest glandular apparatus in the body, and one of its important offices is to secrete the *Bile;* which secretion, as before observed, enters the intestines, near the commencement of the duodenum. The general situation of the human liver, is in the upper part of the abdomen, under the ribs on the right side; from whence it extends more or less to the region of the stomach, and in some instances, even to the left side. The appearance and form of the liver, are too well known to require description here; while to those who are unacquainted with these particulars, they cannot be adequately made known by words. In man, and the greater number of animals, the bile is collected in a small bag, termed from its office, the *gall-bladder*.

The animals wanting a gall-bladder are chiefly vegetable feeders; as the horse and the goat among quadrupeds, the pigeon and the parrot among birds. On the contrary, most amphibia have a gall-bladder; but it exists in few animals lower in the zoological scale. The liver assumes a variety of forms in different animals. In many, and particularly in carnivorous, animals, the liver is more divided than in man: while in ruminating animals, also in the horse, the hog, and others, its divisions are not more numerous than in man. The liver of birds consists of two lobes of equal size.

The *pancreas*, or *sweetbread*, is a large gland, which, in the human body, lies across the upper and back part of the abdomen, behind the stomach; and between the liver and the spleen. The pancreas is composed of numerous small glands, whose ducts unite and form the pancreatic duct. In man the pancreatic duct joins the gall duct, at its entrance into the duodenum, and thus the peculiar secretion of the pancreas is poured into that intestine, commingled with the bile. In animals the pancreas, like the liver, is much varied in its form; and its duct, instead of entering with the biliary duct, often joins the intestinal canal separately; as in the hare and others. In fishes the pancreas is wanting; but what are termed the cœcal appendages, are supposed to have a similar office. The nature of the pancreatic fluid will be considered presently.

The *spleen* in man is situated in the upper and left side of the abdomen. Its shape is oblong, and its colour a deep mulberry; more nearly resembling that of the liver than of any other organ. The spleen has no excretory duct, and its use is very little understood. Among the less perfect animals, the spleen is much smaller than in those whose structure resembles that of man: and where there is more than one stomach, the spleen is always attached to the first. The situation also of the spleen varies in the less perfect animals; thus in the frog, it is fixed in the mesentery.

We proceed to notice, very briefly, the peculiar circulation of the blood in the abdominal viscera; together with the character and agency of that portion of the nervous system, which is connected with the digestive and assimilating functions of animals.

In the general circulation of the blood through an animal body; a large tube or artery, communicating with the heart, is gradually subdivided as it is prolonged from that organ, till its subdivisions finally become imperceptible. While in this state of minute subdivision, the arteries assume the character of veins. The change the veins undergo in their progress, is the reverse of that of the arteries. They unite gradually, and, at length, form one or two principal tubes, which proceed to the side of the heart opposite

to that from which the artery originated. Such is the circulation of the blood through the body generally; the circulation through the lungs is merely a repetition of the same arrangement. Throughout the body, therefore, the general motion of the blood in arteries is from greater to smaller tubes; while in the veins it is from smaller to greater tubes. By a beautiful provision, the veins are also furnished with valves, which most effectually prevent the regurgitation of the blood: without such valves, the blood could scarcely flow in a regular stream. We have introduced these remarks, with the view of stating, that the circulation of the blood through the organs of digestion, presents a remarkable exception to the general circulation of the body. The venous blood, from these organs, undergoes a preliminary arterializing process in the liver, before it is remingled with the venous blood from the rest of the body. That is to say, the veins from the organs of digestion, unite into one large vessel termed the *vena portæ;* which, entering the liver, is there again subdivided, in the same manner as an artery. These ultimate subdivisions of the *vena portæ*, together with the similar subdivisions of the proper artery of the liver, coalesce; and from the blood thus mixed the bile is separated. The coalesced blood-vessels assuming the character of veins, then gradually unite, and at length form two or three large tubes, which empty themselves into the general veins going to the heart; while the hepatic ducts, uniting in like manner, convey the bile to the gall-bladder. Such are the principal facts connected with the circulation of the blood in the abdominal viscera, and with the secretion of the bile. We shall soon have occasion to bring them to the recollection of the reader.

When speaking of organic agents, we noticed the probability of the opinion, that in living beings, there exists a series of agencies gradually raised one above another; each agency having more or less control over all those below it. Now, in the digestive and assimilating functions, we appear to have, as we might expect, the lowest of these agencies. The agencies operating in digestion, and in the first stages of assimilation are, in man, perhaps the same that exist in all organized beings, vegetable as well as animal; and are only a few degrees, as it were, above the agencies of mere inorganic matter. This resemblance is inferred from the phenomena of assimilation; not less than from the peculiar character of the nerves, distributed over the digestive organs; the effects of which nerves, as we shall presently endeavour to show, approach more nearly to those of common chemical agents, than to the effects of any agent belonging to the animal economy. These nerves compose what, from their peculiar structure, are termed the *ganglionic nerves.* In animals of the very lowest kind, the ganglionic nerves alone ap-

pear to exist; and though in the more perfect animals, these nerves are connected with others of a higher character, they always form, by themselves, a peculiar system; the functions of which seem to be of the subordinate character above noticed.

2. *Of Alimentary Substances.*—It may be considered as a general rule, that organized beings adopt, as aliments, substances lower than themselves in the scale of organization; or which, if not originally lower, in some measure become so, by certain spontaneous changes they undergo. There are, of course, innumerable exceptions to this rule; but viewing the whole of animated beings, it seems to be a law of nature. Thus plants, and perhaps the very lowest kinds of animals, have the power of assimilating carbonic acid gas: the powers of assimilation of plants, and of such animals, may also extend to other inorganic compounds of carbon—indeed they seem to derive their chief nourishment from matters of that nature. Higher in the zoological scale, we find that animals almost invariably prey on those that are inferior to themselves, either in magnitude, in organization, or in intelligence; till we arrive at man himself. He, as his necessities, or as his fancies may dictate, appropriates every nourishing substance, even carbonic acid gas; which his stomach, perhaps in common with that of all animals, seems to have the power of assimilating. Of course a lion, or even a crab, can feed on the body of a man, as well as on that of an ox or of an insect. But no one, we presume, will assert, that man is the natural prey or food of these animals; and that alone is the degree of immunity, for which we here contend: for in all the operations of nature, we must try to discover and bear in mind, not the exception, but the rule; otherwise we shall be constantly liable to error.

By this beautiful arrangement in the mode of their nutrition, the more perfect animals are exonerated from the toil of the initial assimilation of the materials composing their frame; as in their food, the elements are already in the order which is adapted for their purpose. Hence the assimilating organs do not require that complication, which they otherwise would have needed; and much elaborate organization is saved. Striking illustrations of this abridgement of organization, are afforded by the differences before mentioned, between the assimilating apparatus of carnivorous and of graminivorous animals. According to the scale which this difference exhibits, we can form some conception of the complication that would be requisite, if such an animal as man were, like a plant, destined to feed on carbonic acid gas; or carburetted hydrogen; or on any other simple compound of carbon.

Another great purpose is effected by this arrangement, without

which, organization, at least as at present constituted, could hardly exist. If organized beings did not prey on each other, their remains would, in time, accumulate in such quantity, as to be nearly incompatible with life; certainly with animal life in its most perfect condition, as it is at present known to us. But by the arrangement that animals are food to each other, not only is an opportunity afforded, for the existence of a greater number of animals, and of a greater variety among them; but the obtrusion of the bodies of animals, in whom life has become extinct, is entirely prevented: nor, is the removal of the dead animal matter the only good accomplished, but many other important results are obtained. To enter upon the consideration of these, would be foreign to our present object: there is, however, one consequence of this system of universal voracity, which more immediately concerns us, since it is of a nature so comprehensive, as to suggest a natural classification of alimentary substances; we allude to the similarity of composition among the staminal principles which constitute the fabric of organized beings.

In our introductory remarks on the chemistry of organization, we showed that organized matters, however apparently dissimilar, yet, chemically speaking, are often nearly related. Of this relation we gave as an example, the composition of the extensive class of substances, denominated the *saccharine group;* all of which, notwithstanding the endless diversity of their appearance, we showed to be essentially alike in their composition, and to consist of carbon associated with water. Saccharine substances are chiefly found in the vegetable kingdom, of which they form the characteristic staminal principle.

Another well known class of bodies, existing both in vegetables and in animals, are those whose character is *oily.* Oleaginous bodies occur in an infinite variety of forms, some being solid, others fluid; yet, in every instance, their peculiar properties are so strongly marked, that we seldom hesitate about their nature. In this distinctness of outward appearance, oily bodies are strongly contrasted with the saccharine group before mentioned; many of which have few *apparent* and sensible properties in common. The composition of all the bodies of this oleaginous group, which we have hitherto had an opportunity of examining in a satisfactory manner, we have found to be essentially the same: they are either composed of olefiant gas and water, or have a reference to that composition. Such is also the composition of the well known proximate principle termed *spirit of wine*, or *alcohol;* into which, most substances belonging to the saccharine group, under favourable circumstances, are readily convertible by the process termed fermentation.

When almost any part of an animal body, (with the exception

perhaps of those matters of a purely oleaginous character) is boiled in water, it is separated into two portions,—one soluble in water, and forming with the water a tremulous jelly, or *gelatine*—the other remaining insoluble, indeed becoming harder, the longer it is boiled ; and which, from the identity of its properties to those of the white of an egg, is denominated *albumen*. These animal principles exist in very different proportions in the different textures ; some of these textures, as the skin, being convertible almost entirely into gelatine ; while others yield comparatively little gelatine, and consist principally of albumen. In no animal compound does gelatine exist as a fluid; hence, it has been supposed to be produced by boiling; but the supposition does not appear to be well founded. One of the most remarkable properties of gelatine, is, its ready convertibility into a sort of sugar, by a process similar to that by which starch may be so converted. Gelatine may be considered as the least perfect kind of albuminous matter existing in animal bodies ; intermediate, as it were, between the saccharine principle of plants, and thoroughly developed albumen : indeed, gelatine in animals, may be said to be the counterpart of the saccharine principle in vegetables. Albumen exists in the fluid state as a component of the blood : small quantities of fluid albumen are also contained in certain animal secretions : but there is much more of the principle in a solid state ; forming what is termed *coagulated* albumen. The blood likewise contains *Fibrin*, another modification of the albuminous principle, in a fluid, or at least in a suspended state: though the most frequent condition of Fibrin, is that of a tough fibrous mass, in which condition, together with albumen, it forms the basis of the muscular or fleshy parts of animals. The *curd* of milk is also a modification of the albuminous principle. Another modification of the same principle is the substance called *gluten ;* this substance though most abundant in vegetables, so far resembles the fleshy parts of animals, as to be, in like manner, capable of separation into two portions, analogous to gelatine and albumen. Neither of these modifications of albumen exhibits the quality possessed by gelatine, of being artificially convertible into saccharine matter ; at least by any known process ; but all of them, including gelatine, differ from the oleaginous and the saccharine principles, in this respect; that they contain a fourth elementary principle, namely, azote. The exact composition of the albuminous group cannot at present be stated.

Such are the *three great staminal principles* from which all organized bodies are essentially constituted. Of these staminal principles it has already been remarked, that, without changing their essential composition, they are capable of assuming an infinite variety of modified forms ; many of which are so peculiar, that it is very difficult to recognize their identity, from their sen-

sible properties. Moreover, these staminal principles, in all their forms, are capable of readily passing into one another, and of combining with each other; at least the organic agents, as we shall see hereafter, have the power of effecting these changes. Further, these staminal principles are all susceptible of transmutation into new principles, according to certain laws: thus the saccharine principle is readily convertible into the acid, termed oxalic; or, under other circumstances, into the modification of the oleaginous principle, alcohol. Though an endless variety, however, of these modifications of the staminal principles exist in different organized beings, accompanied by numerous foreign bodies, the proportion they bear to the staminal principles is very limited; and they are either confined to glandular secretions, or are excrementitious, or extravascular: that is to say, these modifications and combinations form no part of the living animal, though they are attached to it; as in the case of the various products of secretion, the shells of the molluscous tribes, and many others.

The consequence then, to which we before alluded is; that as all the more perfect organized beings feed on other organized beings, *their food must necessarily consist of one or more of the above three staminal principles.* Hence, it not only follows, as before observed, that in the more perfect animals, all the antecedent labour of preparing these compounds *de novo*, is avoided; but that a diet to be complete, must contain more or less of all the three staminal principles. Such, at least, must be the diet of the higher classes of animals, and especially of man. It cannot indeed be doubted that many animals have the power of forming a chyle, and if expressly organized for the purpose, may even live for a while on one of these classes of aliments; but that they can be so nourished for an unlimited time,is exceedingly improbable. Nay, if we judge from what is known from universal observation, as well as from experiments which have been actually made by physiologists regarding food, we are led to the directly opposite conclusion; namely, that the more perfect animals could not so exist; but that a mixture, of two at least, if not of all the three classes of staminal principles, is necessary to form an alimentary compound well-adapted to their use.

This view of the nature of aliments is singularly illustrated and maintained by the familiar instance of the composition of *Milk.* All other matters appropriated by animals as food, exist for themselves; or for the use of the vegetable or animal of which they form a constituent part. But milk is designed and prepared by nature expressly as food; and it is the *only material* throughout the range of organization that is so prepared. In milk, therefore, we should expect to find a model of what an elementary substance ought to be—a kind of prototype, as it were, of nutritious materials in general. Now, every sort of milk that is known, is a mix-

ture of the three staminal principles we have described ; that is to say, milk always contains a *saccharine* principle, a *butyraceous* or *oily* principle, and a *caseous*, or strictly speaking, an *albuminous principle*. Though, in the milk of different animals, these three staminal principles exist in endlessly modified forms, and in very different proportions ; yet neither of the three is at present known to be entirely wanting in the milk of any animal.

Of all the evidences of design in the whole order of nature, Milk affords one of the most unequivocal. No one can for a moment doubt the object for which this valuable fluid is prepared. No one can doubt that the apparatus by which milk is secreted has been formed especially for its secretion. No one will maintain that the apparatus for the secretion of milk arose from the wishes or the wants of the animal possessing it, or from any fancied plastic energy. On the contrary, the rudiments of the apparatus for the secretion of milk must have actually existed in the body of the animal, ready for developement, before it could have felt either wants or desires. In short, it is manifest that the apparatus and its uses, were designed and made what they are, by the great Creator of the universe ; and on no other supposition, can their existence be explained.

The composition of the substances, by which animals are usually nourished, favours the mixture of the primary staminal alimentary principles ; since most of these substances are compounds, of at least two, of the staminal principles. Thus, most of the gramineous and herbaceous matters contain the saccharine and the glutinous principles ; while every part of an animal contains at least albumen and oil. Perhaps, therefore, it is impossible to name a substance constituting the food of the more perfect animals, which is not essentially a natural compound of at least two, if not of all the three great principles of aliment. But it is in the artificial food of man that we see this great principle of mixture most strongly exemplified. He, dissatisfied with the spontaneous productions of nature, culls from every source ; and by the force of his reason, or rather of his instinct, forms in every possible manner, and under every disguise, the same great alimentary compound. This after all his cooking and his art, how much soever he may be disinclined to believe it, is the sole object of his labour ; and the more nearly his results approach to this object, the more nearly do they approach perfection. Even in the utmost refinements of his luxury, and in his choicest delicacies, the same great principle is attended to ; and his sugar and flour, his eggs and butter, in all their various forms and combinations, are nothing more or less, than disguised imitations of the great alimentary prototype MILK, as furnished to him by nature.

CHAPTER III.

OF THE DIGESTIVE PROCESS; AND OF THE GENERAL ACTION OF THE STOMACH AND DUODENUM.

We proceed now to consider the most important function of the stomach, by which the assimilation of the food is begun. But before that function can be well understood, it is necessary to make a few remarks on the influence of water, in modifying the intimate constitution and the peculiar properties of alimentary substances. We have intentionally delayed these remarks, in order that in this place the chemical influence of water might be more strikingly exemplified.

Water enters into the composition of most organized bodies in two separate forms; which must be clearly distinguished, and which it is requisite that the reader should always bear in mind. Water may constitute an *essential* element of a substance, as of sugar or of starch in their dryest states; in which case, the water cannot be disunited without destroying the compound: or water may constitute an *accidental* ingredient of a substance, as of sugar or of starch in their moist states; in which case more or less of the water may frequently be removed, without destroying the essential properties of the compound. Now, a very large number of organized bodies, (perhaps all those to which our present inquiry relates) contain water in both these forms; both as an essential element, and as an accidental ingredient; and in most instances, it is impossible to discriminate between the water that is essential, and that which is accidental. The mode of union, however, among the elements of bodies, in these two states of their combination with water, must be altogether different. Wherein the difference consists, is very imperfectly known; but perhaps the following remarks may throw some light on the subject; at least, they will serve to point out, the nature of these two modes of union, to the reader.

In the first part of this volume, we stated that the molecular, or combining, weights of carbon and of water are, by chemists, usually considered to be represented by the numbers 6 and 9; the weight of hydrogen being *one*. We also advanced the opinion, that the molecules or atoms of carbon and of water, where more than one exist, instead of remaining separate, as is now supposed, are associated together into groups, or supermolecules; and that carbon, water, and similar bodies, always enter into combination, not as single molecules, but as one supermolecule. To illustrate our meaning, let us take as examples, the state of combination of the molecules constituting the different varieties of sugar.

Sugar from the cane, in its purest state, and when as free as possible from accidental water, is, according to the present language of chemists, composed of 9 atoms of carbon and 8 atoms of water. Now, we suppose these 9 atoms of carbon, and 8 atoms of water, to be associated into two supermolecules, weighing (9×6) 54, and (8×9) 72, respectively. So that, we conceive a molecule of sugar from the cane to be a binary compound, of a supermolecule of carbon weighing 54, and a supermolecule of water weighing 72. Again, the sugar of honey, according to the present language of chemists, is composed of 9 atoms of carbon, and 12 atoms of water ; or, according to our view of molecular arrangement, the sugar of honey is composed of two supermolecules, one of them, carbon, weighing 54, as in the sugar of the cane—the other, water, weighing no less than (12×9) 108. A similar statement may be given of the composition of Lignin, another of the saccharine class of bodies. This substance, which, in all its various forms appears to consist essentially of equal weights of carbon and water, may be said to be composed of 9 atoms of carbon, and 6 atoms of water ; or, according to our views, of two supermolecules weighing (9×6) 54, and (6×9) 54, respectively. Hence, the saccharine class of bodies may be represented in the following manner :—

Carbon.		Water.	
54	+	54	Lignin.
54	+	72	Cane Sugar ; Wheat Starch.
54	+	108	Sugar of honey ; Arrowroot.

The molecular constitution of the saccharine bodies, above stated, may be compared with that of Vinegar. According to the present language of chemists, vinegar, in its purest and most detached form, is composed of 4 atoms of carbon, and 3 atoms of water ; or, according to our views, of two supermolecules weighing (4×6) 24, and (3×9) 27, respectively. Thus, the molecular constitution of these two different states of vinegar may be represented as follows :—

Carbon.		Water.	
24	+	27	Absolute vinegar.
24	+	36	Crystallized or solid vinegar.

We have stated the composition of vinegar, in order to draw the attention of the reader, to the difference between the supermolecule of the carbon in that acid, and the supermolecule of the carbon in the saccharine class of bodies ; a difference to which these two classes of bodies probably owe the striking differences in their sensible properties. But why the supermolecule of carbon should be 54 in bodies of the saccharine class, and why this supermolecule should in general exist in the self-attractive form,

and produce sweetness; or why the supermolecule of carbon in vinegar should be 24, and why this supermolecule should have such a tendency, as it exhibits, to assume the self-repulsive form, and to produce sourness; we do not know, and probably shall never be able fully to explain. Still, there can be little doubt that a careful and philosophical examination of the phenomena, would go far to dispel the obscurity in which the subject is now involved.

Such are the principles, which, we conceive to regulate the chemical union of organic, and indeed of all other compounds; and if chemical union be so regulated, the inferences are most curious and important. With these inferences in general, we have at present no concern: but those more particularly relating to alimentary compounds are the following:—

First. We would draw the attention of the reader to the contrast between the two supermolecules of carbon, and of water, constituting sugar; the supermolecule of carbon being uniform throughout the whole saccharine class, while the supermolecule of water is that which is variable. Now, there is reason to believe that this contrast holds in other instances; and that in different organized substances of the same kind, the supermolecule of carbon, or of some of its compounds, remains the permanent and *characteristic* element; and that the different modifications are produced by variations in the supermolecule of water; which may be called the *modifying* supermolecule.

Secondly. The manner of the operation of the modifying agency may be thus illustrated. If to a portion of cane sugar, we add that quantity of water, which, by an easy calculation, we learn is necessary to be united with it, in order to its conversion into sugar of honey; we find that we cannot succeed in producing such conversion; and that the excess of water which had been added, flies off, and leaves the cane sugar in its original state. On the other hand, if we apply heat to the sugar of honey; though we may indeed drive off part of the water essentially associated with that sugar, we do not obtain sugar similar to that of the cane; but we destroy, or altogether decompose the sugar of honey. These facts, therefore, show that the excess of water, constituting the difference of the sugar of honey from the sugar of the cane, is really in some state of essential union, incapable of being imitated; while, in the cane sugar, the water may exist as an accidental ingredient only. In fact, according to our views of molecular arrangement; *every individual supermolecule of the weaker sugar contains a portion of this excess of water, as an essential element of its composition.* Hence such water cannot be separated from any compound, without destroying the entire crasis, or constitution, of its molecular elements; which, as in the

case of the sugar of honey, we find, by experiment, to be the result. On the other hand, we suppose the molecules of accidental water *to form no essential element of the molecules of sugar, or of other bodies, but to be only loosely associated with them;* and hence, the ease with which accidental water may be separated without destroying such bodies.

Thirdly. It may be advanced as a general rule, that the larger the number, representing the weight of the supermolecule of any compound substance; whether such number represent the characteristic, or the modifying supermolecule; the more easily may that compound substance be decomposed. Thus, the sugar of honey is more easily decomposed—is much less permanent, than the sugar of the cane; and the purest sugar, is much less permanent than Lignin. In like manner, when water is the modifying element of any compound, as it is in most organic compounds, the larger the number representing the supermolecule of the water, the greater, for the most part, is the solubility of the compound.

Fourthly. There are, at present, no chemical terms corresponding to those differences of composition, which we have brought under the notice of the reader. Now, the terms *strong* and *weak*, which in commerce, distinguish the different varieties of sugar, are sufficiently expressive; we have, therefore, made choice of them, to denote the similar varieties of other organic compounds. Thus, when we speak of a *strong* compound; we mean that its constituent supermolecules are, like those of strong cane sugar, less complicated than the supermolecules of a *weak* principle, like those of the sugar of honey. Again, there are no terms expressive of the conversion of a strong substance into a weak substance, or the contrary. To express such conversion we have adopted the terms *reduction*, and *completion*.

In the above illustrations of the modifying influence of water in organic compounds, we have selected sugar as our example, solely from its being the most familiar. But, as we have more than once noticed, exactly the same laws appear to regulate the composition of all organized bodies. Thus in the *strong*, fixed, and solid, oils or fats, the characteristic supermolecule of which, as we have already said, has some relation to olefiant gas; the modifying molecule of water is very small, perhaps, in some oleaginous bodies, is even a submolecule. Whereas, in alcohol, which is the *weakest* condition of the oily principle, the weight of the modifying supermolecule of water is more than half that of the olefiant gas, and alcohol is perfectly soluble in water.

Gelatinous and albuminous substances, also, exhibit precisely the same variations. The *strong* tenacious glue, employed in the arts, is made from the firmer parts of the hides of old animals; while the gelatinous size, or weak glue, is made from the skins

of younger and more delicate animals. These two varieties of glue differ from one another, in the weights of the modifying supermolecules of water which enter into their composition. In general, it may be observed, that the substances composing the frame of old and of young animals, differ chiefly in the weights of their modifying supermolecules of water; and that the dissimilarity of their properties, is chiefly owing to this difference.

If the reader has clearly apprehended, and will bear in mind, the principles that have now been stated, as regulating the chemical constitution of organized bodies, and the modes in which they are influenced by their modifying constituent, water; he will be able to accompany us in the observations we are about to offer; and he will thus, more especially, be able to form a general conception of the *chemical* operations of the stomach. The operations of the stomach, viewed as a whole, may be stated as follows:—

1. The stomach has the power of dissolving alimentary substances, or, at least of bringing them to a semifluid state. This operation seems to be altogether chemical; and is probably effected by *reducing* the properties of these alimentary substances.

2. The stomach has, within certain limits, the power of changing into one another, the simple alimentary principles, which have been described in the last chapter. Unless the stomach possessed such a power, that uniformity in the composition of the chyle, which we may imagine to be indispensable to the existence of every animal, could not be preserved. This part of the operations of the stomach, appears, like the reducing process, to be chemical; but not so easy of accomplishment; it may be termed the *converting* operation of the stomach.

3. The stomach must have, within certain limits, the power of *organizing* and *vitalizing* the different alimentary substances; so as to render them fit for being brought into more intimate union with a living body, than the crude aliments can be supposed to be. It is impossible to imagine, that this organizing agency of the stomach can be chemical. This agency is vital, and its nature is completely unknown.

1. *Of the Reducing Powers of the Stomach.*—In order to render more intelligible that function of the stomach, which it owes to its reducing power, let us endeavour to trace the series of phenomena, which appear to arise during the conversion of simple albuminous matter into the albumen of the chyme; without taking into account any other change.

When a portion of fluid albumen, as of the white of an egg, or of milk, is introduced into the stomach of an animal, as of a dog, it instantly becomes solid; or, in ordinary language, is *coagulated*. This coagulation is probably a mere chemical change; for the

same change, would, under similar circumstances, take place out of the body. That is to say, if the white of an egg, or milk, were mixed with a fluid more or less acid, like that which exists in the stomachs of animals while the food is undergoing the process of digestion; it would be coagulated. There may be, however, and probably is, some object in the change produced by coagulation; since the stomachs of animals are fitted to operate chiefly on solid matters. Admitting the object of the change, we can hardly consider it to be essential to the subsequent process; for gelatine, a staminal alimentary principle, nearly resembling albumen in its composition, undergoes, under similar circumstances, no such solidifying change. The albumen thus solidified by the stomach into a mass or curd, is soon altered further; more especially that part of the mass, with which the membrane of the stomach is in contact. The curdy mass assumes a gelatinous appearance; then each portion is successively more and more softened, till at length, the whole becomes nearly fluid, and after some additional modifications, gradually passes into the state of chyme. Through all these apparent changes, however, the albumen has undergone no real change. What was introduced into the stomach as albumen, is still albumen in the chyme; at least chemists have pronounced it so to be. Yet it has assumed an appearance altogether different. The albumen of the egg, out of the stomach, may be coagulated by heat, into a firm elastic solid. The albumen of the chyme is indeed coagulable by heat, but its coagulation is so imperfect, and so wanting in tenacity, as to offer a striking contrast with the coagulated albumen of the egg. What then, in the stomach, has happened to the albumen? Viewing only its susceptibility of coagulation, the albumen has merely become chemically combined with a portion of water. The solid and tenacious albumen has, by this combination with water, been reduced to the *weakest* possible state—to the delicate state, as it were, of infancy; in short, to a state precisely analogous to that of the weak sugars, and other organic compounds, as compared with the strong and perfect varieties of the same substances, described in the preceding chapter.

Such is, we believe, an accurate account of the merely solvent or reducing powers of the stomach. We have next to show the means by which this solution or reduction is effected.

The process of combining different substances with water, and of thus reducing them from a stronger to a weaker condition, may, in some instances, and to a certain degree, be effected artificially. But in no instance do we appear to be able to invert the process; or to complete an organic compound, by again separating the water. For example, we can, in some respects, make a strong sugar weak, but we cannot change a weak into a

strong sugar; though such a change, within certain limits, seems to be, to the organic agents, just as easy, as the reducing process.

The different operations of cookery, as roasting, boiling, baking, &c. have all a reducing effect; and may, therefore, be considered as preparatory to the solvent action of the stomach. Of these operations, Man's nature has taught him to avail himself, and they constitute the chief means by which he is enabled to be omnivorous: for, without such a preparation, a very large portion of the matters which he now adopts as food, would be completely indigestible. By different culinary processes, the most refractory substances, can often be rendered nutritious. Thus, by alternate baking and boiling, the woody fibre itself may be converted into a sort of amylaceous pulp; not only possessing most of the properties of the amylaceous principle, but capable of being formed into bread. The culinary art engages no small share of attention among mankind; but, unfortunately, cooks are seldom chemists; nor indeed do they understand the most simple of the chemical principles of their art. Hence, their labour is most frequently employed, not in rendering wholesome articles of food more digestible, which is the true object of cookery; but in making unwholesome things palatable: foolishly imagining that what is agreeable to the palate, must be also healthful to the stomach. A greater fallacy can scarcely be conceived; for, though by a beautiful arrangement of Providence, what is wholesome is seldom disagreeable; the converse is by no means applicable to man; since those things which are pleasant to the taste are not unfrequently very injurious. Animals, indeed, for the most part, avoid, instinctively, all unwholesome food; probably because everything that would be prejudicial, is actually distasteful to them. But as regards man, the choice of articles of nourishment has been left entirely to his reason.

In order to illustrate the importance of a judicious adaptation of cookery, we may observe, that the particular function of the stomach, now under consideration, namely, the dissolving or reducing function, is liable to very great derangements. In some individuals, the reducing power is so weak, that their stomach is almost incapable of dissolving solid food of the most simple kind. In such a state of the stomach, a crude diet of the flesh of animals in a hardened state, or of other compact substances, is little else than poisonous; while the same animal and vegetable matters often agree well, if reduced to a pulpy state. On the other hand, as in the disease termed Diabetes, the solvent powers of the stomach are often inordinately increased; and every article of food is dissolved and absorbed almost as soon as it is swallowed. In such cases, a diet and a mode of preparation are required, directly the reverse of those which are found to be so beneficial, when

there is a debility of the solvent powers; and aliments which are firm and solid, but at the same time nutritious, must be chosen.

Regarding the intimate nature of the agency, by which the combination of alimentary substances with water is effected in the stomach, we cannot be said to possess much certain knowledge. This combination appears to be chiefly owing to the agency of a fluid, secreted by the stomach; the glands for the formation of which fluid, are most numerous toward the pyloric orifice. The aliment having been previously broken down by mastication, and having received an admixture of saliva and of other fluids, is brought into contact with the fluid secreted by the stomach; by which secretion, or by some other energy there in operation, the food that has been introduced into the stomach is associated with water; and thus becomes itself more or less a fluid. Of this important secretion of the stomach, *chlorine*, in some state or other of combination, is an ingredient; it would seem a necessary ingredient; for the secretion in its healthy state, always contains more or less of chlorine, the powerful influence of which elementary principle, seems mainly to contribute towards effecting the union of the food with water. The chlorine, thus so indispensable to the reducing process, is perhaps more frequently the subject of derangement, than anything concerned with the assimilation of the food. It often happens that instead of chlorine, or a little free muriatic acid, a large quantity of free muriatic acid is elicited; which not only gives rise to much secondary uneasiness, but more or less retards the process of reduction itself. The source of this chlorine or muriatic acid, must be the common salt which exists in the blood: to suppose that it is generated, is quite an unnecessary hypothesis. The chlorine is therefore secreted from the blood; and it may be demanded, what is the nature of the agency, capable of separating that element from a fluid so heterogeneous as the blood? We are acquainted with one agent that exerts such a power, namely, electricity; and this agent, as we formerly observed, seems to be employed by the animal economy for its operations, in the same manner, and on the same principles, as the materials themselves are employed, from which the animal body is constructed. Perhaps, therefore the decomposition of the salt of the blood may be fairly referred to the immediate agency of this principle, electricity. But here the question arises, What becomes of the soda from which the muriatic acid has been disunited? The soda remains behind, of course, in the blood, and a portion of it no doubt, is requisite to preserve the weak alkaline condition essential to the fluidity of the blood. But the larger part of this soda is probably directed to the liver, and is elicited with the bile in the duodenum, where it is thus again brought into union with the acid, that had been separated from the blood, by the stomach.

These observations, illustrating the importance of common salt in the animal economy, seem to explain, in a satisfactory manner, that instinctive craving after this substance, which is shown by all animals.

Admitting that the decomposition of the salt of the blood is owing to the immediate agency of galvanism; we have, in the principal digestive organs, a kind of galvanic apparatus, of which the mucous membrane of the stomach, and perhaps that of the intestinal canal generally, may be considered as the acid or positive pole; while the hepatic system may, in the same view, beconsidered as the alkaline or negative pole. Whether such galvanic action be admitted or not; and the admission is of no very great importance; what we have above stated may be received as a simple expression of the facts, in so far as they relate to the saline constituents of the blood. Moreover, be the nature of the energies what they may, by which these changes are effected; along with these changes, and probably by the aid of the same energies, other very important changes or processes are carried on, to some of which we shall presently have occasion to allude. In the mean time, we may close this section by observing that there is strong reason to believe, that the solvent power, which we have described, or some power having a great resemblance to it, exists not only in the stomach, but in every part of an animal body. In all animals there are minute tubes, called absorbents, which originate in every part of their bodies, and at length uniting, enter the sanguiferous system along with the chyle. Now, the office of these tubes, is to remove all those portions of the animal frame, which after having performed their several functions, require to be withdrawn. Of course, before solid parts can be thus removed, they must be dissolved, (*digested* in fact;) and such solution, in many instances, is probably effected, as it is in digestion, by combining these solid parts with water. This supposed analogy between the solvent powers of the stomach, and those which must prevail all over the body, seems to be strongly confirmed by that similarity of structure and of function existing between the lacteals and the absorbents: they indeed form but one system. We shall resume this subject hereafter.

2. *Of the Powers of Conversion possessed by the Stomach.*—Though the proportions of the different ingredients of the chyle, as ultimately formed, are liable to be much varied, according to the nature of the food; yet, whatever the nature of the food may be, the general composition and character of the chyle, remain always the same. The stomach must, therefore, be endowed with a power or faculty, the agency of which is to secure this uniform composition of the chyle, by appropriate action upon such mate-

rials, as circumstances may bring within its reach. Two, indeed, of the chief materials from which chyle is formed, namely, the albuminous and the oleaginous principles, may be considered to be already fitted for the purposes of the animal economy, without undergoing any essential change in their composition. But the saccharine class of aliments, which form a very large part of the food of all animals, except of those subsisting entirely on flesh, are by no means adapted for such speedy assimilation. Indeed, one or more essential changes must take place in saccharine elements, previously to their conversion, either into the albuminous, or into the oleaginous principles. Most probably, under ordinary circumstances, these essential changes are altogether chemical; that is to say, they are such as do take place, or rather, such as would take place, if the elements of the substances thus changed in the stomach, could, out of the body, be so collocated, as to bring into action the affinities necessary to produce these changes. Thus, as we know, the saccharine principle spontaneously becomes alcohol; which, as has been stated, is merely an oleaginous body of a weak kind. When, therefore, in the stomach, it is requisite that sugar be converted into oil, it is probable that the sugar passes through precisely the same series of changes it undergoes, out of the body, during its conversion into alcohol. We cannot trace the conversion of sugar into albumen; because we are ignorant of the relative composition, and of the laws which regulate the changes, of these two substances. The origin of the azote in the albumen, is likewise at present unknown to us; though in all ordinary cases, it seems to be appropriated from some external source. That the oleaginous principle may be converted into most, if not into all the matters necessary for the existence of animal bodies, seems to be proved by the well-known fact, that the life of an animal may be prolonged by the absorption of the oleaginous matter, contained within its own body. Thus, many hybernating animals, when they retire in autumn, to sleep during the winter, are enormously fat. But while they sleep, their fat is gradually removed; till they awake in the spring quite divested of it, and in a state of inanition.

The reader will have remarked that we have made use of the term *ordinary circumstances;* and perhaps it may not be amiss to explain what meaning we attach to that term.

When an animal is duly fed according to that diet which is natural to it, and for which its organization has been adapted; a regular and *ordinary* series of changes takes place within the animal, and the alimentary matters are converted into chyle. But one general characteristic of organized beings is that within certain limits, and for a certain time, they possess the power of varying their habits, and of accommodating themselves to circumstances. Under *extraordinary* circumstances, therefore, extraordinary

changes must, and do, take place. In some instances, these changes out of the ordinary course, are to an extent altogether astonishing; and such as defy our utmost calculation. The assimilating organs appear even to decompose principles which are still considered as elementary, nay, to form azote or carbon; so that it is impossible to define what, on an emergency, these organs are capable of doing. But what is thus done by these organs on an emergency, will usually, be found to constitute an exception to what they do in ordinary; their ordinary mode of action being always that which is most simple, and which is thus to be considered as the rule.

3. *Of the Organizing and Vitalizing Powers of the Stomach.*—In this part of our investigation, we meet the real difficulties we have to overcome in explaining the operations of living beings. The whole of the great and essential changes which alimentary substances undergo, may, and perhaps will be, traced by care and attention; but all beyond, will probably remain for ever unknown to us. Now at least, it may be truly said, that though we understand, in some degree, the chemical changes; of the vitalizing influence we know absolutely nothing. There is, however, every reason to believe that vitality is imparted through the agency of the living animal itself. For though, from the natural composition of alimentary substances, they be to a certain extent, fitted for the purposes of the animal economy; yet, alone, they are incapable of uniting themselves with the animal frame; and unless the living economy contribute likewise its share of the labour, the future work of assimilation will be incomplete.

Of the Changes the Food undergoes in the Duodenum.—We alluded in general terms to the bile and the pancreatic fluids, when we were treating of the organs by which they are secreted. We have now to consider, more particularly, the nature of these secretions, and their share in the performance of the functions of the duodenum.

With the yellow colour, and the intensely bitter taste of the *bile*, all are familiar: we need not, therefore, dwell on the sensible properties of the secretion, but proceed to notice its chemical composition. The chemical composition of the bile is very heterogeneous, though not perhaps so heterogeneous as has been represented; since it is probable that many of the ingredients said to be contained in the secretion, are products that have resulted from the methods employed in its analysis. Bile, like all animal fluids, is composed essentially of water; but the solid matters contained in the bile, are nearly altogether formed from one or more proximate principles, in which carbon and hydrogen predominate. These proximate principles exist simultaneously, if not in conjunction with soda, and with various salts of soda, besides other substances. The properties of the bile vary somewhat in different animals;

but in all animals its essential characters remain wonderfully similar.

We are much less acquainted with the properties of the *pancreatic fluid*, than with those of the bile. The nature of the pancreatic fluid was formerly supposed to be very analogous to that of the saliva; but recent observations have shown that it contains albumen, and a curdy substance. The pancreatic fluid is, for the most part, in a slight degree acid, and holds in solution matters of a saline nature, closely resembling those found in all animal fluids.

When the food that has undergone the first process of digestion in the stomach, quits that organ, and enters the duodenum, some other changes of a very remarkable kind take place. If the food originally contained no albuminous matter, no albumen is developed in the stomach; but immediately on the entrance of the semi-fluid mass into the duodenum, and its mixture with the bile and the pancreatic fluids; albuminous, and other chylous matters, become distinctly perceptible. At the same instant, those fluid parts, which in the stomach were acid, are so far altered, by the addition of the bile, and the pancreatic fluids, as to become neutral, or almost neutral: some gas is frequently extricated; and that portion of the food which is destined to be excrementitious, is evidently separated. The albumen, which is thus found to exist in the *chyme*, (as the food is termed, after it has been acted on by the stomach, and has entered the duodenum), may be partly derived from the pancreatic fluid, which, as we have already mentioned, has been said to contain albumen. But the quantity of albumen, and of other proximate principles of the chyle, that are found in the contents of the duodenum, at some distance onward from the pylorus, is much too great to be explained in this manner. Indeed, the properties, as well as the quantity, of the albuminous matters, show, beyond a doubt, that the albuminous matters are developed from the food, and constitute the chyle, which is subsequently taken up by the lacteals.

Such are those most interesting, and at the same time obvious, phenomena, that are observed in different animals, in which the changes produced on the food by the action of the duodenum have been examined. These phenomena appear to vary considerably, according to the nature of the food; but so far as we can understand the phenomena, under every change of food, the essential character of the changes which the food undergoes in the duodenum, remains unaltered. That is to say: the acid formed in the stomach, combines, in the duodenum, with the alkali of the bile; the albuminous principles are developed; and the excrementitious matters are, more or less perfectly, separated. Of the nature of the more recondite and vitalizing changes which take place in the

duodenum ; we are in the same state of complete ignorance, as we are of the similar changes which take place in the stomach, and probably shall long so remain.

In the preceding remarks on the different processes which take place in the stomach and duodenum, and which are necessary for the conversion of the food of an animal into the living material of its body ; we have endeavoured to distinguish between what, to a certain extent, is within our powers of comprehension, and what is completely beyond them. It remains to be observed in conclusion, that though the three great and essential processes of digestion, namely, the reducing, the converting, and the organizing processes be sufficiently distinct from each other ; yet it is not to be understood that they take place in succession, or in the order in which they have been described. The fact is, that all these processes go on at the same time; and as soon as a portion of food begins to be dissolved, its future changes seem to be determined. If it be necessary that the portion of food undergo an essential change, that change is accordingly begun. If no such change be required, the organizing process itself begins simultaneously with the reducing process. The consequence of this union of the digestive processes is, as we have stated, that the staminal principles are all developed in the chyle ; as soon as the excrementitious matters are separated by the biliary and pancreatic fluids.

Of the Functions of the Alimentary Canal, beyond the Duodenum.—Compared with the functions of the stomach and duodenum, the functions of the succeeding portions of the alimentary canal, as far as we can judge, are unimportant. The digested mass passes from the duodenum into the jejunum, and ilium ; though before the food reaches the end of the ilium, the whole of the chyle contained in it, has been absorbed into the apertures of the numerous tubes named *lacteals.* These tubes open in greater or less number, into the whole interior surface of the three portions of the alimentary canal, along which the food is moved from the stomach to the colon. From the ilium, the undigested or excrementitious matters proceed into the cœcum ; in which cavity, in some animals, as for example, in the horse, even these excrementitious matters appear to undergo a second digestion ; but in all animals, the contents of the cœcum have a very different aspect from those of any part of the alimentary canal, nearer to the stomach. The mass of excrementitious matters continue their course from the cœcum into the colon, where they are still further changed. The nature of these changes, however, is not well understood, though they are probably of no small importance in the animal economy. Finally, all the nutritious portions of the

food, having entered into the system of the animal, nothing remains but what is entirely excrementitious.

Such is a short sketch of the phenomena of digestion and assimilation, in as far as these processes are effected by the stomach and the alimentary canal. The phenomena suggest the following reflections :

First. With regard to the nature and the choice of aliments, and the modes of their culinary preparation ; it follows from the observations we have offered ; that, under similar circumstances, those articles of food, which are the least organized, must be the most difficult to be assimilated : consequently, that the assimilation of crystallized, or very pure substances, must be more difficult, than the assimilation of any others. Thus, pure sugar, pure alcohol, and pure oil, are much less easy to be assimilated, than substances purely amylaceous ; or than that peculiar condition or mixture of alcohol existing in natural wines ; or than butter. In these forms, the assimilation of the saccharine and the oleaginous principles is comparatively easy. Of all crystallized matters, pure sugar is perhaps the most easily assimilated ; but every one is taught by experience, that much less can be eaten of articles composed of sugar, than of those composed of amylaceous matters. In some forms of dyspepsia, the effect of pure sugar is most pernicious; perhaps fully as pernicious as that of pure alcohol. Nature has not furnished either pure sugar or pure starch; and these substances are always the results of artificial processes, more or less elaborate ; in which, as in many of the processes of cookery, man has been over-officious ; and has studied the gratification of his palate, rather than followed the dictates of his reason. In many dyspeptic individuals, the assimilating and preservative powers of the system, are already so much weakened, as to be unable to resist the crystallization of a portion of their fluids. Thus in gouty invalids, how often do we see chalk-stones formed in every joint? Now, with so little control over their own fluids, how can they reasonably hope to assimilate extraneous crystallizations? If, therefore, such an invalid, on sitting down to a luxurious modern banquet, composed of sugar, and oil, and albumen, in every state of combination, except those best adapted for food, would pause a moment, and ask himself the question ; Is this debilitated and troublesome stomach of mine, endowed with the alchemy requisite for the conversion of all these things into wholesome flesh and blood? He would probably adopt a simpler repast, and would thus save himself from much uneasiness. The truth is, that many of the elaborate dishes of our ingenious continental neighbours, are scarcely nutritious, or designed to be so. They are mere vehicles for different stimuli—different ways, in short, of gratifying that low animal propensity, by which

so many are urged to the use of ardent spirits, or of various narcotics. In one respect indeed, namely, that of reducing to a state of pulp those refractory substances which we have before mentioned, the culinary processes of our neighbours are much superior to ours; but in nearly every other respect, and most of all, in the general use of pure sugar and pure oil, their cookery is eminently injurious to all persons who have weak digestion. On the other hand, in this country, we do not in general pay sufficient attention to the reducing processes of the culinary art. Everything is firm and crude; and though the mode of preparation be less captivating; the quantity of indigestible aliment is quite as great in our culinary productions, as in those of France.

We are not, however, writing a treatise on cookery or dietetics; but in treating of the function of digestion, it is impossible altogether to pass over these important subjects. The foregoing observations are merely intended as illustrations of those general principles which often regulate the choice, and the preparation of the food of mankind, in a state of civilized society. Reason is too little followed, the indulgence of the palate is the sole object; so that the organs of digestion already enfeebled, and incapacitated for the assimilation, even of the most proper nourishment, are daily oppressed with a task for which they are altogether unequal. The consequence is, that though for a time the labour be sustained, the digestive energies are at length overcome. The dyspeptic being passes half his days in misery; his offspring inherit their parents' constitution; and if they persist in a like course of slow poison; after a few generations, the race becomes extinct,—"his name even is cut off from among men!" Providence has gifted man with reason; to his reason, therefore, is left the choice of his food and drink, and not to instinct, as among the lower animals: it thus becomes his duty to apply his reason to that object; to shun excess in quantity, and what is noxious in quality; to adhere, in short, to the simple and the natural; among which the bounty of his Maker has afforded him an ample selection; and beyond which if he deviates, sooner or later, he will suffer the penalty.

Secondly. The view we have now taken of the processes of digestion, removes in some degree that mysterious character with which they have been invested; and by lessening the field of our inquiry, brings us nearer to our object. We had previously known, that the articles employed as food by animals are essentially composed of three or four elements. But we have now learnt, that all the more perfect of those matters on which animals subsist, are compounds of three or four proximate principles; the whole of which compounds, except one, are, in their essential characters, identical with those composing the frame of the animals themselves.

We have also learnt, that owing to this identity of composition, many animals are saved the labour of forming these proximate principles from their elements; and have only to re-arrange them, as their exigencies may require. The task of forming the proximate principles is thus left to the inferior animals or to plants; which are endowed with the capacity of compounding them from matters still lower than themselves, in the scale of organization. Hence there is a series, from the lowest being that derives its nourishment from carbon and carbonic acid, up to the most perfect animal existing. Each individual in the series preferring to assimilate those immediately below itself; but having on extraordinary occasions, and in a minor degree, the power of assimilating all, not only below, but above itself, in the system of organized creation.

We stated that the immediate influence employed by the organic agent is probably galvanism, or the common agents that operate among inorganic matters; and that the digestive apparatus, viewed as a whole, seems to be arranged on galvanic principles. We wish, however, our readers clearly to understand, that we consider the organic agent residing in the ganglionic system of nerves, and employing the electric agency, to be *not* electricity itself; though the agency is probably the lowest kind existing in animal bodies, and only, as it were, one degree above the agencies of inanimate matter. We dwell on this point the more, because from deficient recollection of what electricity is, and what are the living powers acting through the nervous system of animals, it has been maintained, nay, has even been endeavoured to be experimentally proved, that these nervous powers are identical with the powers of electricity. It is impossible to imagine a greater fallacy. Admitting that electricity, properly directed, could change the proximate elements of the food into those of chyle; can we imagine this principle to vary spontaneously its mode of operation, so as to produce the same chyle from every sort of aliment—that electricity is an *intelligent* agency acting with a certain object? Besides, if the nervous agency be identical with electricity, how different must be its functions in different nerves; in one nerve, for example, digesting and assimilating the food; in another conveying sight; in a third conveying sound; in the brain itself, shall we say, actually thinking! As to the experiments, on which it has been attempted to rear this most untenable opinion, they prove nothing whatever; and are easily explained on other principles. Such explanation would be foreign to our present object, were we to introduce it here. But there is one observation, which has always appeared to us conclusive against this fancied identity of the nervous energy with electricity; and with which, we shall close what we have to offer, regarding the present subject. Most

persons are aware that there are certain fishes endowed with the power of evolving electricity, and of communicating a smart shock to other animals. Now, in all the fishes in which this power resides, as in the Torpedo, there is a complicated apparatus, extending over a large portion of the fish's body, expressly for the purpose of forming the electricity, which the fish communicates; thus, proving beyond a doubt, that mere nerves are not sufficient to develope electricity; and that, when electricity is wanted, an express and peculiar organ is as requisite for its secretion or formation, as for the secretion and formation of any other product of the animal economy.

The reflections suggested by the facts we have now detailed, will be given in conjunction with those suggested by the facts to be detailed in the next chapter.

CHAPTER IV.

OF THE PROCESSES OF ASSIMILATION SUBSEQUENT TO THOSE IN THE STOMACH AND ALIMENTARY CANAL; PARTICULARLY OF THE CONVERSION OF THE CHYLE INTO BLOOD. OF RESPIRATION, AND ITS USES. OF SECRETION. OF THE FINAL DECOMPOSITION OF ORGANIZED BODIES. GENERAL REFLECTIONS, AND CONCLUSION.

1. *Of the Passage of the Chyle from the Alimentary Canal into the Sanguiferous System; and of the Function of Absorption generally.*—The Chyle, as we have already said, is taken up from the alimentary canal, by numerous minute tubes, named *lacteals;* these tubes being part of the system of similar tubes, which arise from all parts of the body, and are termed *absorbents.* The whole of the absorbing tubes, after passing through various glands, at length unite into one or two of larger size; that on the left side being by far the largest, and known by the appellation of the *thoracic duct.* These larger absorbent tubes pour their contained fluids into the veins named the *sub-clavian;* and thus into the general mass of the blood. The exact nature of the changes which the chyle and the lymph undergo in their passage through these tubes, is not well understood. One change appears to be, that the chyle, as first formed in the alimentary canal, is to a certain extent, *completed,* or freed from water, during its course through the lacteals: for though, when the chyle is mixed with the blood, its albuminous principles are much less perfectly developed than those of the blood itself; yet their developement, on their mixture with the blood, is more perfect, than when the chyle is first taken up from the alimentary canal.

The matters conveyed from the other parts of the body, by the tubes of the general absorbent system, have, by most physiologists, been supposed to be of an excrementitious character. That some of the absorbed matters are excrementitious, is very probable; arguments may, however, be adduced, to show, that the whole of the matters absorbed are by no means excrementitious; but that they are repeatedly consigned to the uses of the vital agency: every new organization raising them, as it were, a step higher, and qualifying them for those refined and ulterior purposes; for which the crude chyle can hardly be imagined to be at once adapted.

The circumstances favouring the above opinion, which we are now desirous to mention, are—

First. It is unreasonable, and contrary to every thing we know respecting the operations of the animal economy, to suppose that the chyle should be separated from one kind of excrementitious matter, in the alimentary canal; in order to be immediately mixed again with other excrementitious matters, in the chyliferous tubes. It is, therefore, a just inference, that if the matters contained in the absorbents are really and wholly excrementitious, they would be carefully kept apart; and would be removed from the system by some other means, than by tubes united with those conveying the nutritious fluids.

Secondly. By admitting that the fluids contained in the absorbent tubes possess a highly animalized character, the design of their union with the crude and imperfectly animalized chyle, becomes apparent: the fluid in the absorbents will be seen to execute an important and necessary office; by raising the vital character of the chyle, and qualifying it, for becoming a part of the general mass of the blood. We thus obtain a cogent reason, why the fluids taken up from the internal surface of the alimentary canal, should be mingled with those that are absorbed from other parts of the body; a mixture which is inexplicable, on the hypothesis of these absorbed fluids being wholly excrementitious.

Thirdly. The gradual developement of the staminal principles of animal bodies, by repeated organizing processes, fully accords with those general views of the operations of nature which, throughout this work, we have endeavoured to illustrate; and which lead to the general conclusion, that the operations of nature are never abrupt, but always slow and gradual. Further, it is more reasonable to conceive, that matters already assimilated to the animal body, are better fitted for its immediate uses; than those which, like the chyle, have only received an imperfect assimilation.

Fourthly. Many animals can and do live, for a considerable time, on substances contained in their own bodies. Thus hybernating animals, as previously stated, have the ability to assimilate

principles of the blood, gelatine is not mentioned. In fact, though further, those matters which have already become part of themselves ; consequently, such a faculty of progressive organization as we have supposed, actually exists ; and *a sort of digestion is carried on in all parts of the body, to fit for absorption and future appropriation, those matters that have been already assimilated.* Were it necessary, other arguments to the same effect might be added : but we shall at present delay the further consideration of the assimilating character of the whole absorbent system ; that we may recur to it again, in a succeeding part of the present chapter.

2. *Of the Blood.*—The blood is that well-known fluid pervading the tubes, named from their function the *blood-vessels ;* which tubes are extended more or less over every part of an animal. We have already described the general distribution of the blood-vessels ; and shall now confine ourselves chiefly to the properties of the blood itself.

The chyle, as we have stated, is poured into the general mass of the blood near the heart ; and from the heart is almost immediately propelled through the lungs. The chyle, thus set in motion, is not only united thoroughly with the blood ; but undergoes those other important changes, by which its final conversion into blood is accomplished. The exact nature of these changes is unknown ; but they are evidently of a completing character—that is to say, the weak hydrated ingredients of the chyle, are freed from a portion of the water with which they were associated ; and are transmuted into the strong albuminous matter of the blood.

The chief constituents of the blood are essentially albuminous. Blood contains albumen in three states of modification : namely, *albumen*, properly so called ; *fibrin ;* and the *red particles.* In addition there are *oily* matters ; besides various minute portions of other animal matters, and *saline* matters, all dissolved, or rather suspended, in a large quantity of water. The following short table exhibits the relative proportions of the constituents of human blood to each other, as they exist in most individuals.

ONE THOUSAND PARTS OF HUMAN BLOOD CONTAIN

Of Water - - - - -	783,37
Fibrin - - - - -	2,83
Albumen - - - - -	67,25
Colouring matters - - - -	126,31
Fatty matters, in various states - -	5,16
Various undefined animal matters, and salts -	15,08
	1000,00*

The reader will not fail to remark, that among these constituent

* Le Canu ; mean of two analyses.

existing most abundantly in various animal structures, *gelatine is never found in the blood, or in any product of glandular secretion.* We formerly noticed that gelatine appears to rank lower than albumen in the scale of organized substances: and we may now add, that a given weight of gelatine, contains at least three or four per cent. less carbon, than an equal weight of albumen. The production of gelatine from albumen must, therefore, be a *reducing* process. We shall presently have occasion to revert to these facts. In the mean time we subjoin the few observations we have to offer, on the organization or structure of the blood.

The organization of the blood is even more wonderful than its chemical composition, and is still less understood. The red portion of the blood, for example, is composed of innumerable minute globules, varying in size in different animals; and in all instances, highly organized: the real structure indeed of these globules is very imperfectly known; but they are generally supposed to be formed of solid colourless nuclei, within red vesicles. The fibrin, also, is diffused through the mass of the blood in a state of equally minute subdivision; though the particles of the fibrin are colourless, and their magnitude much less than that of the red particles. From this inferiority in size, some physiologists have been led to think, that the colourless particles of the fibrin, are identical with the nuclei of the red particles. During the life of an animal, the particles of the fibrin, as well as the red particles of its blood, seem to be in a state of extreme self-repulsion; by which self-repulsion, the union of these particles is prevented; except as the economy of the animal may require, and may determine. After death, however; or in blood withdrawn from the body of a living animal, the property of self-repulsion, more especially among the fibrinous particles of the blood, ceases, and they readily cohere: this cohesion is termed the *coagulation* of the blood. Much beautiful design is probably concealed under that peculiar organization of the blood, to which it owes its coagulating tendency. One result of the coagulation of the blood, indeed, is as obvious as it is important; namely, the prevention of hæmorrhage. If the blood did not coagulate, the existence of animals would be most precarious; as on the slightest injury, they would be liable to bleed to death.

3. *Of Respiration.*—The function of *Respiration*, or breathing, is one of the most important in the animal economy, and cannot, like many of the other functions, be suspended; the interruption of that function being immediately destructive of life. When we described the phenomena of the circulation of the blood, we observed, that the blood, in passing through the lungs, is exposed to the action of the atmospheric air. Now, during this exposure of the blood to the atmospheric air, it undergoes certain changes. The blood from the right side of the heart, when it

enters the lungs, is of a dark red colour; it is then dispersed, in a state of most minute subdivision, through the ultimate vessels of the lungs, and in these vessels is brought into contact with the atmospheric air, and becomes of a bright red colour. In other words, the blood changes in the lungs its *venous* appearance, and assumes the character of *arterial* blood. The blood thus arterialized, returns to the left side of the heart, and from that organ, is propelled through the whole arteries of the body. In the minute terminations of the arteries, the blood again loses its florid hue, and, reassuming its dark red colour, is returned to the veins, to the right side of the heart; to be exposed as before to the influence of the atmospheric air, and to undergo the same succession of changes.

On examining the respired air, a remarkable alteration of its properties is found to have taken place; a portion of its oxygen has disappeared, and a similar bulk of carbonic acid gas, has been substituted. With respect to the origin of this carbonic acid gas, there have been various opinions. Formerly, the greater number of physiologists maintained, that carbon, in some form, was excreted by the lungs; and that this excreted carbon, uniting with the oxygen of the inspired air, was converted into carbonic acid gas. No one imagined that oxygen gas could be passing inwards through the membrane of the lungs, while carbonic acid gas was, at the same time, passing outwards, through the same membrane. Accurate observations have, however, demonstrated, that such a simultaneous passage of gases really takes place through the membrane of the lungs; and the observations are not confined to the two gaseous bodies in the lungs; but are applicable to all gases whatever, under similar circumstances. In consequence of these observations, it seems now to be generally admitted, that the oxygen of the atmospheric air is absorbed by the blood, and, in some unknown state of combination, reaches the extreme subdivisions of the arteries; where it is united with a portion of carbon, and forms carbonic acid gas: that this carbonic acid gas is retained in some unknown state of combination in the venous blood; till, in the lungs, it is expelled, and oxygen is absorbed in its stead; according to the laws which regulate the diffusion of gaseous bodies, formerly explained. Further, with the carbonic acid gas, a large quantity of aqueous vapour, as we have stated, is at the same time separated.

It would be foreign to the objects of this treatise, were we to enter further into the reasons for the view we have given of the phenomena of respiration. These reasons are many and strong; and seem indeed to prove clearly, that the changes which the blood undergoes, during its circulation through the body, are as we have described them. We shall, therefore, assume that our

view of respiration is correct; and shall offer a few remarks on the attendant circumstances, and on the consequences of respiration.

First. To what influence are we to ascribe the different colours of arterial and of venous blood? The opinion formerly held, was, that the arterial colour arose from the absorption of oxygen; and the venous colour from the presence of carbon. But recent observations seem to show that the change in the colour of the blood during its circulation, if not entirely independent of oxygen, is much influenced by the saline matters; particularly by the common salt, which the blood contains: and that the dark colour of venous blood, is principally owing to the presence of carbonic acid gas.

Secondly. What is the source of the carbonic acid in venous blood, and of the aqueous vapour that is expelled from the lungs? These questions cannot be answered with certainty. But some observations lately made, have induced us to believe, that the *conversion of albuminous matters into gelatine*, is one great source of the carbonic acid in venous blood. Gelatine, which, as before observed, contains three or four per cent. less of carbon than albumen contains, enters into the structure of every part of the animal frame, and especially of the skin: the skin indeed consists of little else besides gelatine: it is most probable, therefore, that a large part of the carbonic acid of venous blood is formed in the skin, and in the analogous textures. Indeed, we know that the skin of many animals gives off carbonic acid, and absorbs oxygen; in other words, performs all the offices of the lungs; a function of the skin perfectly intelligible, on the supposition that near the surface of the body, the albuminous portions of the blood are always converted into gelatine. With respect to the aqueous vapour thrown off from the lungs: we have every reason to believe, as before stated, that much of this vapour is *derived from the chyle*, in its passage through these organs; and that by such separation of water, the *weak* and delicate albumen of the chyle, is converted into the *strong* and perfect albumen of the blood; according to the principles detailed at the commencement of this chapter.

Thirdly. What are the uses of the continual extrication of carbonic acid from living animals; and could not a little superfluous carbon have been thrown off from their bodies in a more simple manner? The precise use of the constant evolution of carbonic acid, or how it is effected, we know not; but one great use which has been assigned to this evolution, is, the formation of the heat of the body; and not only the power of forming that heat; but also the power of varying it according to circumstances—a power so characteristic of organized life. Out of the body, carbon does

certainly give off heat on combination with oxygen. Hence, it has been maintained with great plausibility, that the same combination, within a living body, may give origin to its heat; though it must be confessed, that there are some difficulties about this view of the origin of animal heat, which detract considerably from its likelihood. Moreover, it is exceedingly probable, that though the evolution of carbonic acid gas, may be one of the means possessed by the animal economy for generating heat; there are yet other means, the nature of which at present are quite unknown.

The quantity of carbon thrown off by the lungs, is very abundant; but has probably been much overrated. Philosophers have, for instance, calculated that the lungs of a man of ordinary size expel, in the course of twenty-four hours, eleven ounces of carbon; a quantity more than equal to that contained in six pounds of beef.* If carbon be indeed thrown off from the lungs so copiously; it must be produced within the body. It is difficult to account for the quantity of carbon thrown off, even on the lowest estimate. We are, therefore, necessarily obliged to conclude, that more solid matter is every day expelled from the body by the lungs, than in any other manner. Hence the probability of the opinion formerly noticed, that the matters taken up by the absorbents, and by the veins, enter successively into the formation of various parts of the animal frame; instead of being removed, immediately after their absorption, as at present is generally supposed. For it seems hardly possible to reconcile, with the quantity of food, the great quantity of carbon that is expelled from the lungs alone; much less, what must be expelled if all the matter taken up by the absorbents be likewise considered excrementitious.

4. *Of Secretion.*—From the blood, are formed, by means of peculiar apparatus, all those numerous products termed *Secretions;* not only so unlike each other, but so unlike the fluid from which they are originally separated. Some of these secreted products appear to be little else, than a separation of certain matters already existing in the blood. Other secretions have no resemblance to any ingredient of the blood: consequently, in the glandular structure, by which these secretions, so dissimilar to the blood, are formed, the blood must undergo some essential change. In the present state of our information, however, we must content ourselves with a limited insight into the nature and

* According to an elaborate analysis, by Berzelius, the muscle of an animal contains 77 per cent. of water, and 23 per cent. of other matters. Supposing, what is near the truth, that 22 of these 23 parts consist of albumen, and that this albumen contains half its weight of carbon; which in round numbers is a sufficiently neat approximation; it follows, that 100 parts of the muscular fibre of animals, contain about 11 parts of carbon; so that 11 ounces of carbon must represent 100 ounces of beef; that is, upwards of six pounds as stated in the text.

the causes of secretory action. We see that secreted products are of two kinds; that some of the matters separated by animal bodies are evidently thrown off, on account of their noxious qualities; are, in fact, *excretions;* which could not be retained without proving fatal to the life of the animal from which they are detached: while others again, are as obviously intended for further objects, and for the performance of various subordinate actions in the living system; are in fact, *secretions;* properly so called. But as we have stated, we are still perfectly unacquainted with the intimate nature of these changes; though it is probable that a careful examination of the phenomena, would throw much light on their general character; and display evidence of the most consummate design.

5. *Spontaneous decay of Organized Bodies.*—It remains finally to close this work with a few observations on the spontaneous, and inevitable decay, of all those things that are produced by organization; after they have been removed from the influence of the organic agents, by which the combination of their constituent principles was effected.

The organized beings that inhabit this globe, however numerous, have a very small relation to the magnitude of the globe, and seem to occupy its surface only. We have seen that the elements forming the structure of these beings, are not only combined in different proportions, but that they appear, in many instances, to undergo further decomposition into ultimate forms of matter, which, out of a living body do not, and perhaps, in the present constitution of the universe, cannot, exist in an isolated state. Owing to this diversity in the composition of organized beings from that of inorganic matter, and to other causes which will readily occur to the reader, organized beings and their laws, are in continual opposition to the general laws, by which inorganic matter is governed. To counteract, therefore, these opposite laws, and to maintain the existence of organized beings, require the unremitting efforts of the organic agency. But at length these efforts are exhausted; the contest ceases; when the general laws of inorganic nature prevail, and speedily reduce, to their original state of existence, the atoms which had been incarcerated in the living frame.

The spontaneous decay of organized beings is usually termed the *putrefactive* process; and some substances are much more prone than others, to undergo that change. As might be expected; those substances whose constitution is most simple, as the oils, and bodies of a like nature, are also the most permanent; while substances more compounded, especially those which include azote, are exceedingly liable to putrescent change. For such changes a certain degree of heat and of moisture appear to

be necessary: since in a temperature below the freezing point of water, or in a perfectly dry state of the atmosphere, even animal substances may be preserved unchanged during any length of time. The phenomena attending the dissolution of different kinds of organized matters are of course different; but in every instance, the tendency is toward the formation of compounds more simple than the matter decomposed; that is to say, of compounds whose existence, out of a living body, is not incompatible with the present state of the globe. Those matters which, in a warm and damp air, seem first to be loosened from organic combination, are those foreign bodies we formerly mentioned, as existing, in every part of the structure of organized beings, in some unknown but active self-repulsive state. Hence, during putrescent action, arises the formation of sulphuretted and phosphoretted hydrogen, and of other undefined compounds of the same elements: and these gaseous compounds, chiefly, produce the very offensive odour of putrefaction. At the same time, there are formed, carburetted hydrogen, oil, acetic acid, ammonia, and last of all, carbonic acid gas and water; while the azote is extricated in a gaseous condition. Finally, both vegetable and animal matters, but vegetable matters more especially, are reduced to the state of mould. The mould from vegetable matters, consists principally of carbon, in combination with a little oxygen or hydrogen: the mould from animal products, consists of similar matters, mixed with a little azote, and the usual saline ingredients of organized substances. In this form of mould, the remains of vegetables and of animals, as was before stated, constitute the food of plants; by which they are again organized, and thus go through the same series of changes.

We may here pause for a moment, and, on account of the general reader, briefly recapitulate the most striking facts, that have been detailed in the present, and in the preceding chapters.

In the first place, the *mechanical arrangements* for reducing the food of animals to the proper degree of comminution, are wonderfully varied, according to the peculiar qualities of that food. In the graminivorous and granivorous tribes, for example, the teeth are literally instruments for grinding or triturating herbaceous matters, and seeds. In carnivorous animals, such a structure would be useless: the teeth, therefore, are suited only for cutting, or tearing. In knawing animals, the teeth present a totally different structure, but at the same time are admirably fitted to the habits of the animal. Occasionally, as in the fowl tribe of birds, the grinding apparatus is placed, not in the mouth, but in the stomach itself; this organ being, as it were, expressly contrived for trituration; while some of the functions it performs in other animals, are transferred to contiguous parts.

The structure and mechanism of the stomach, and of the ali-

mentary canal, then claim our particular attention. In carnivorous animals, whose food requires comparatively little assimilation, the alimentary canal is short, and of a simple structure. On the other hand, in vegetable feeders, that canal is long and complicated; but perfectly adapted for macerating their food, and for extracting from it, everything that can be converted into nourishment. Nor is there an adherence to any model, but the whole is throughout varied; as if in order to demonstrate the power and the wisdom of Him by whom they were contrived. Thus the alimentary canals of the cow, and of the horse, are formed on entirely different models; though the food of both animals be nearly the same.

We proceed in the next place, to the consideration of the *chemical changes*, which the food undergoes in the stomach and duodenum. In these changes we discover arrangements not less wonderful, indeed more wonderful, than in those of structure and of mechanism. The variety of forms, assumed by bodies having the same essential composition, produces a latitude, in the choice of diet, which is almost infinite: at the same time, the organs being endowed with the power to discriminate all these differences, and to act on the ultimate principles of bodies; elaborate, from all these various forms of matter, the same uniform resulting chyle. The power by which the stomach is enabled to effect these astonishing changes, is the power which it possesses, of associating the different alimentary substances with water; the power, in short, of dissolving or digesting them. This dissolving power seems to be exerted through the agency of chlorine, derived from the common salt in the blood; at least, chlorine is always present in the stomach, during the act of the solution of the food; though the precise mode in which it operates, is still unknown. Contemporaneously with the act of solution of the food, such essential changes take place in its composition, as are requisite for perfecting the future chyle.

The stomach having accomplished its office, the digested mass enters the duodenum; where the series of changes is continued in a manner equally wonderful. In the duodenum, the digested mass is brought in contact with the biliary and the pancreatic fluids. The alkali of the bile unites with the acid, with which the food had been mingled during its digestion in the stomach; the excrementitious parts, both of the food, and of the bile, are separated or precipitated; while at the same time, the proper chylous principles are eliminated, in a condition appropriate for their absorption by the lacteals.

There are two divisions of those minute tubes, that compose what is termed the absorbent system of animals;—the lacteals—and the absorbents properly so called. The ultimate ramifications of the lacteals, originate from the internal surface of the alimen-

tary canal, where they take up the digested, and partly assimilated, element or chyle. The ultimate ramifications of the proper absorbents, originate from all parts of the body ; and are enabled to take up, by some peculiar process, every component of the body, solid as well as fluid, in the same manner as the chyle is taken up by the lacteals.

The fluid obtained from the lacteals, and that obtained from the proper absorbents, are both alike albuminous. The albumen of the chyle, as we have formerly shown, is produced in the stomach and duodenum, while the food is undergoing the process of digestion. But whence is the albumen derived, that is found in the proper absorbents? The animal body we know to be composed of a great variety of matters, among which gelatine predominates. Now, since albumen only is found in the absorbents, it follows, that before the gelatine of the body is taken up by the absorbents, it is re-converted into albumen : in other words, the absorbed gelatine undergoes a process, entirely analogous to that which gelatine, and other matters, undergo in the stomach and duodenum, during the process of digestion. Hence, the digestive process, instead of being confined to the stomach and duodenum, is actually carried on without intermission, in all parts of a living animal body.

The two kinds of fluid albumen derived from these two sources; that is to say, the crude chyle in the lacteals, and the highly animalized lymph in the absorbents, are at length commingled; and form one uniform fluid of an intermediate character, adapted for becoming a part of the general mass of the blood. The character however of this fluid, when it becomes part of the blood, though albuminous, is still very *weak ;* that is to say, the fluid consists of albumen, holding a large proportion of water in a state of essential combination. By a beautiful arrangement, as soon as this weak albuminous fluid is mingled with the blood, it is hurried through the lungs; where it undergoes a remarkable change. In the lungs, the water, which is in essential union with the weak albuminous matter of the chyle, is separated and expelled along with the carbonic acid gas, which is continually escaping from these organs; and at the same time, the weak and delicate albuminous matter of the chyle, is converted into the strong and firm albuminous matter of the blood. We are thus brought to consider the process of respiration.

The blood, in its course through the lungs, emits carbonic acid gas, and assumes a florid *arterial* colour. At the same time, according to the principles of gaseous diffusion, the blood absorbs, in the lungs, a portion of oxygen from the air of the atmosphere. The oxygen thus absorbed, remains in some peculiar state of union with the blood, (Query, as oxygenated water, or some analogous compound ?) till the blood reaches the ultimate termi-

nations of the arteries. In these minute tubes the oxygen changes its mode of union; it combines with a portion of carbon, and is converted into carbonic acid; which carbon must be derived from the albuminous principles of the blood. Two distinct alterations take place during the union of the carbon with the oxygen: a portion of the albumen contained in the blood is supposed to be reduced to the state of gelatine; which gelatine is appropriated toward the renovation of those textures whose composition is chiefly gelatinous: at the same time, the carbonic acid which had been formed from the reduced albumen, unites with the blood, communicates to that fluid its dark *venous* colour, and is transferred to the lungs; where it is expelled from the system, along with a portion of aqueous vapour, derived principally from the weak albumen of the chyle; as formerly explained.

The blood is the source, not only of all the constituent principles of animal bodies, but likewise of all the various *secretions;* many of which differ altogether, in their properties, from those of the primary fluids, and perform secondary offices, of great importance in the animal economy. Other products separated from the blood, are purely *excretions;* as, for instance, the carbonic acid gas from the lungs; which could not be retained in the animal system without destroying life.

Finally, the life of the animal becoming extinct, the essential properties of the matter of which it is composed, resume their natural action, and speedily restore the elements to their original condition.

Such is a summary of those operations of living bodies, which, in the present and in the preceding chapters, we have endeavoured to illustrate; and though our insight into those operations be very imperfect, it is amply sufficient to satisfy us, of the infinite wisdom by which they are directed; and that the unknown, must be far more wonderful than what has been disclosed. Most of the facts on which we have dwelt, are of a character so obvious, that they require only to be understood, in order to be admitted among the proofs of the great argument of design; at least, by all, but those who affect to deny that argument. We therefore leave to the reader, the application of facts, so obviously demonstrative of design; and proceed to offer a few remarks on certain general arrangements of organized and living beings, relatively to those of inorganic matter.

First. In considering the economy of organized beings, one of the circumstances most calculated to arrest our attention, is the extraordinary skill manifested in the disposal of the various parts of the organized system, with regard to each other. As an instance, on the great scale, may be noticed, the mutual relation and dependance of plants and animals. Thus, as we formerly pointed out, carbonic acid gas constitutes the chief food of plants;

and we now see, that nearly the whole of the superfluous carbon produced by the operations of the animal system, is actually thrown off in the form of carbonic acid. Plants, therefore, on the one hand, supply the chief nourishment to animals ; while that gaseous matter which is separated by the animal economy, and which if retained within animals, would to them be fatal, constitutes, on the other hand, the chief food of plants. Nor in these two respects only, are the two great systems of organization mutually dependent ; for unless plants consumed the carbonic acid gas which is formed by animals ; this deleterious compound would probably accumulate in the atmosphere, so as to destroy animal life ; while it is doubtful, whether the present races of vegetables could exist, if carbonic acid gas were not formed by animals. Again, the general scheme of Providence, for the nourishment of animals, claims our especial notice. Animals have not only been destined to prey on each other : but all created beings are the food of those progressively higher than themselves, in the scale of organization. By this wise arrangement, the labour of the assimilating power has been greatly diminished ; and by the same means, that accumulation of dead animal remains which soon would be overwhelming, is entirely prevented. Even in the fabric of individual animals, and in the operations carried on within them, the same wise purposes of mutual relation and dependance are observable. Thus, whether we contemplate the repeated employment of the same materials ; or the various important ends, in many instances accomplished by the same process ; we discover, throughout, the utmost abridgement of labour ; so that the greatest possible effect, is every where produced, by the simplest possible means.

Secondly. The general subserviency, of the mechanical arrangements of the frame of organized beings, to the chemical operations that are carried on within them, is of still greater interest and importance, than even those arrangements have been shown to be. Wemay view an organized being as a piece of intricate machinery, adapted to the physical, and the chemical properties of matter. The adaptation of this machinery to the physical properties of matter, belongs to another department. Our attention is directed solely to the chemical adaptations. The performance of the chemical changes within organized beings, through the interposition of mechanical arrangements, as has been stated in a former part of this work, establishes, beyond a doubt, that these chemical changes have a real existence. Thus, when we witness such a display of elaborate arrangements, as are exhibited in the mechanism of the digestive organs, and of the circulating system ; the purpose of which arrangements is merely to produce a few chemical changes in the food, and in the blood ; it is evi-

dent that the chemical changes so produced, must be at least as real, as the mechanical structure, by means of which they are effected. Hence the adaptations of mechanical arrangements, in the structure of organized beings, to the pre-existing chemical properties of matter, affords an evidence of design, not less impressive than unequivocal. The most determined sceptic cannot assert that there is any *necessary* relation, or indeed any relation whatever, between the mechanical arrangements, and the chemical properties to which they administer. There is no reason why the chemical changes of organization, should result from the mechanical arrangements, by which they are accomplished: neither is there the slightest reason, why the mechanical arrangements in the formation of organized beings, should lead to the chemical changes of which they are the instruments. From what cause, then, arose the association of the chemical changes with the mechanical arrangements? How were the chemical operations of digestion and of respiration brought into union with the mechanical apparatus of digestion, and with the circulating system? The co-existence of things so entirely dissimilar, and having no kind of mutual relation, can be explained only on the supposition that *a will exists somewhere;* and also a *power* to *execute that will.* The existence is thus unavoidably acknowledged of a Being, who knowing every pre-existing chemical property of matter, and willing to direct these properties to a specific object, has contrived for that purpose an apparatus admirably fitted to attain His object. Such is the explanation—the only possible explanation, of the subserviency of mechanism to chemistry, in the processes of organic life. And what is this explanation, but our *argument of design*, in terms that seem absolutely irresistible?

Thirdly. That perpetual renovation and decay to which all organized beings are liable, may be considered as a part only of the great round of changes, which we witness in everything that has been created. The world itself, as we have seen, appears to have been, at intervals, subjected to changes involving even the fundamental laws by which it is governed. Nothing, therefore, belonging to the world, can reasonably be expected to be permanent. Had there been even an approach to such permanence, the beautiful adaptations of organized beings to the pre-established laws of inanimate matter, and all the other wonderful arrangements we have described, could not have been manifested as they now are. Besides, to the changes we ourselves undergo, we are indebted for the greater part of the enjoyments of our life. If none died, none could be born; and the present arrangements of human society could have no existence. There would be none of the pleasing relations of parent and offspring; none of the agreeable variety of childhood, of youth, of maturity, and of age, experienced by

every individual; which, with all the other numerous relations of society, incidental to the persons of different individuals, contribute so largely to human happiness. Were man exempt from change; whether the rest of the world were supposed to be progressive, as it is; or whether it were stationary, as regards him; the same uniform and dull monotony would prevail, the same want of motive. In short, with our present constitution and feelings, perpetuity and uniformity would be physically and morally impossible.

But why, it has a thousand times been asked, why has the world been so constituted? Why this unceasing round of change? Whence its origin? What its object?—Such questions, the Great Author of the universe alone can answer. But as within those narrow limits by which our observations are bounded, wherever we can trace His designs, we see that His works are never without an object; we cannot doubt that in determining their perpetual change, there is no less an object; though it be above our comprehension. By placing immaterial and intelligent beings, for a time, in personal connection with matter, He has indeed communicated to them a knowledge of those properties of matter which so strikingly display His wisdom and power; and this may have been one of His objects:—but to speculate further on points so utterly beyond our capacity, would be presumptuous: for who can "know the mind of God, or who hath been His counsellor?"

We have thus given a brief outline of what has been denominated the Chemistry of organization; in other words, an account of those changes and combinations which, through the operation and the agencies of inorganic matter, organic agents are capable of effecting. The information it has been in our power to give, though imperfect, we have shown to be amply sufficient, not only to demonstrate the astonishing wisdom, and foresight, with which organized beings, in as far as we can understand them, have been contrived and formed; but the infinitely higher perfection of both these attributes, requisite to impart to organization that vitality, the nature of which so entirely surpasses our conception.

We shall now close this volume with a few observations on the future progress of chemistry; on the means by which this science may be applied to physiological research; and on the tendency of physical knowledge in general.

Chemistry, as we pointed out in the introduction to this treatise, forms the connecting link between those branches of human knowledge which are founded on quantity, and those which are derived solely from experience. All our experimental knowledge that is not chemical; for instance, all that physiology which re-

lates to the phenomena of life, is wholly removed from the logic of quantity, and depends entirely on observation. Now so far as the logic of quantity is applicable, so far are we certain of our conclusions, as certain at least as we are of our own existence, or that we see and hear. But when this logic cannot be applied, our conclusions are no longer such as *must* be—no longer follow from our premises a necessary consequence; but are only, for the most part, such as *may* be; that is to say, have no more than that degree of probability which arises from the evidence we have of the truth of the phenomena or events, forming our premises.

In all knowledge depending on mere observation or experiment, what we know, is grounded on our own observation and experience, or on the observation and experience of others. What we ourselves observe, we too often observe very imperfectly; or do not understand, when observed. But phenomena or events, the knowledge of which we are obliged to receive at second hand, on the *testimony* of others; and which may have been observed through the distorted medium of ignorance or of prejudice—may even have been wilfully misrepresented—of these we have a still less assurance. If a phenomena or event has happened only once, and be therefore historical; we are under the necessity of acquiescing in its truth, or of estimating its probability, according to the rules of evidence. If the phenomenon or event be of frequent occurrence, or if its nature be such, that it is capable of being brought under our own observation; in order to remove our uncertainty, we endeavour to observe it ourselves; in short, we make an experiment. Such is the method we pursue, in obtaining all that knowledge which is the result of mere observation. The different events succeed one another, but we know not wherefore; we see not their mutual connexion. We believe that an event will, *probably*, follow another event; because the one event has always followed the other, or because of some other probability; but we cannot discover that *necessary* connexion between the two events, which so irresistibly leads us to determinate conclusions, where we can apply the laws of quantity.

The foregoing remarks may be viewed as a continuation of those offered in the introduction to this volume, and chiefly relate to the progress of chemistry. Chemistry being a science of observation, we can form but a very imperfect conception of its future progress; because, we cannot, by reasoning, anticipate the discovery of those chemical facts which are yet concealed. The progress that chemistry, within these few years, has made, is truly astonishing; and when a more rigorous mode of observation shall be adopted—in short, when chemistry shall be brought more under the control of the laws of quantity—a control that will be exer-

cised, at least indirectly—it is impossible to foretell the degree of perfection which chemistry, as a science, may attain. But, for many years yet to come, the progress of chemistry must depend solely on experiment; and its cultivators must be satisfied with the comparatively humble office, of discovering the actual chemical changes, which bodies effect on each other.

Since, then, in knowledge derived from observation, an acquaintance with *what exists*, and with *what is done*, is indispensable; to obtain a clear, accurate, and unequivocal conception of these things, is the first duty of every observer, and of every experimentalist. Nor is there any observer, or experimentalist, however unpretending, who may not add to the stock of ascertained facts; so varied and inexhaustible are the stores of nature. Another duty of every one who engages in observation or experiment, is to become the faithful historian of what he witnesses; to narrate the event or phenomenon in plain and intelligible language, employing only terms of a definite meaning; so as to convey to others a just notion of what he has seen. We say a *just* notion; in the greater number of instances, a *perfect* notion is impossible; because what is seen, cannot be expressed by language. But to give a just notion; that is to say, a notion which, though incomplete, *has no foreign or false gloss*, is within the power of every observer; and to give such a notion of the facts he narrates, ought to be his chief study. One testimony of so faithful a witness is often invaluable, and worth a thousand vague and inaccurate observations; which are only calculated to bewilder, or to mislead; and thus are worse than useless.

The next rule which an interpreter of nature should bear in mind, is *not to attempt too much at first;* but in order to establish a sure foundation for his succeeding labours, he ought to be content with obvious and unexceptionable facts; and so to arrange these facts, as to lead to others. To elicit novel and prominent facts, is the lot of few; and any one may happen to be so successful. But all, as before stated, may *investigate truth;* and thus contribute more or less towards the advancement of knowledge. Moreover the humblest contributors may rest assured, that they imperceptibly raising a structure, which will sooner or later include the conspicuous labours of their more fortunate coadjutors; in which structure, these labours will indeed still appear conspicuous; though their importance will be diminished as the fabric is extended around them.

The remarks just made, have especial reference to the application of chemistry to physiology. The cautious and judicious application of chemistry to physiology has already effected much, and is capable of effecting still more. Indeed it is hardly possible to say, how far chemistry may extend physiological knowledge.

But chemistry, in its present state, in order to be made really useful, must be applied in a manner the most guarded and sparing—must, indeed, be rigidly confined to the ascertainment of *what the living principle does;* and *how it operates on inorganic principles.* With the living, the animative properties of organized bodies, chemistry has not the smallest alliance; and probably will never, in any degree, elucidate these properties. The phenomena of life, are not, even remotely, analogous to anything we know in chemistry, as exhibited among inorganic agents. The great error of chemists, therefore, has been their attempting to apply that science to explain phenomena, for the explanation of which, chemistry, as we have said, is totally valueless. Such perversion of the reasoning powers, has too much prevailed among physiologists in all ages. In the earlier ages, heat was considered the principle or life. In later times, electricity has been discovered; and to electricity, the same functions have been ascribed. Life, according to other philosophers, is motion. But the progress of science has dispelled all these illusions: the origin of the obscure and evanescent principle of life, must be sought elsewhere. By heat, for example, many wonderful things may be accomplished; but heat will not act itself. The powers of electricity are still more wonderful than those of heat: but electricity, we know to be governed, in its mode of action, by certain laws, and that it gives no sign of intelligence. In the same manner, life, as we are acquainted with it, cannot exist without motion; but motion can exist without life. Life and motion, consequently, are not synonymous terms; nor can we conceive the existence of motion, without a mover. In short, the living principle, as already pointed out, is something different from, and superadded to the common agencies of matter; over which, to a certain extent, it has a control. Thus, the phenomena exhibited by the mysterious agency of life, are strictly comparable only with one another; and have no relation to any inorganic phenomena.

But the desire of the Physiologist to ascribe to the agencies of inorganic matter, those operations carried on within living bodies, is merely a display of that innate propensity of the human mind, which leads us to seek after First Causes. The conceptions of the physiologist regarding the principle of life are the same, therefore, as the conceptions of mankind in all ages regarding the Great First Cause—the Deity himself. The poor untutored savage "sees God in every cloud, and hears him in the wind." The complacent philosopher smiles at the credulity of the savage, and perhaps defies "the laws of nature!" Both are alike ignorant; nor is the imagined Supreme Being of the untaught savage, in any degree, more absurd, than the imagined Pantheism of the philosopher. The winds we know can be referred to other causes, to

which they are immediately owing: so with the progress of knowledge, the "laws of nature," have been found to merge, and will continue to be found to merge, into other laws, still more general; thus proving that these laws are, all alike, mere delegated agencies. Hence the tendency of knowledge, and of its due application, is to abstract the attention from inferior things, and to fix the mind on the source of all knowledge and of all power—the GREAT FIRST CAUSE; who exists and acts throughout the universe; whom we can approach only, by studying His works; and whose works, an eternity, will be inadequate to explore.

APPENDIX

CONTAINING

ADDITIONAL NOTES AND EMENDATIONS.

Page 33. "Forces of Gravitation."—Many objections have been offered to the term *vis inertiæ* adopted by Newton. Indeed, to speak of mere *inertia*, or *inactivity*, as a force, is obviously absurd. We have always agreed with those who think that the term *inertia* has been unfortunately chosen; since *inertia* expresses only one quality, as it were, of that which *is attracted*, or which *reacts*, in nature. But, we fully acquiesce in the opinion, that whatever *resists attraction* or *reacts*, is as appropriately named a force, in a certain sense of that term, as that which *attracts* or *acts;* and such resistance is in all instances, virtually considered as a force by the mathematician, however he may choose to designate it.

Page 42. We fear the terms *chemical* and *cohesive axes* are not quite legitimate. We have employed these and other familiar modes of expression, such as "*forces* of gravitation," "polarizing *forces*," &c. above alluded to, either on account of the general reader, for whom this work is principally intended, or for the sake of analogy.

Page 50.—Elementary form of electrical energies, &c. Throughout this work, as just observed, we have adhered as much as possible to the common language of chemistry. We conceive, however, that chemical, and the allied, phenomena admit of being expressed in terms of hypotheses, of which the chief are the following:—

1. That every portion of matter attracts, and is attracted by, every other portion of matter, according to laws which have obtained universal assent.

2. That all matter, as it is known to us, exists in the condition of molecules; which molecules we consider to be virtually spheres or spheroids.

3. That all the spherical or spheroidal molecules, when unimpeded, revolve on their axes, with velocities, which in molecules having the same weight, are under similar circumstances, fixed and definite; but which velocities, in molecules of different

weights, increase, according to a law which need not be here specified, as the weights of the molecules diminish.

4. That the molecules of the imponderable matters, light and heat, are vastly less than those of any ponderable substance; hence, that the velocities of the molecules composing these imponderable matters, are inconceivably rapid; further, that the substance of these molecules is either fluid or elastic, so that they become more or less oblate, in proportion to the intensity of their motion.

5. That the imponderable molecules of light and heat obey the same laws by which ponderable matters are governed; but that these imponderable molecules are capable of pervading and operating within ponderable molecules, whose motions they influence by the intensity of their own motion; and that the molecules of imponderable matters thus appear in the character of agents.

Page 64, *note*.—The term "homogeneous" light is a misprint: we mean the unaltered light of the sun. Light and heat, and indeed all self-repulsive fluids may be supposed to possess two kinds of self-repulsive power: that which is common to them as fluids; and that which depends upon the action of individual molecules of such fluids when in certain positions, and which positions, these molecules are naturally inclined to assume under certain circumstances, particularly when in motion. Hence the marshalling of the individual molecules of light, supposed in this note, probably do not exist, at least so as to become apparent, till the light approaches, or passes through some ponderable medium. These phenomena of light, may perhaps, be rendered more intelligible, by what appears to happen with respect to gaseous bodies. The rapidity of the motion of gaseous bodies, through any permeable medium, increases as their specific gravity diminishes. Thus the force with which, the lightest of these bodies, hydrogen, struggles to escape through any porous matter, is almost incredible; according to Mr. Graham's experiments, sufficient to raise a column of water from 20 to 30 inches. This rapidity of motion seems only explicable on the supposition, that the individual molecules of the gas, in their passage through narrow canals, are guarded from external and lateral influence; and are thus enabled to assume that position which is natural to them, and in which their mutual self-repulsion is the greatest possible. Hence, a single row of self-repulsive molecules of gas (or other self-repulsive fluid) passing through the minute apertures of a porous vessel into a vacuum, or what is analogous, into another gas having different self-repulsive powers, may be compared to a row of bullets urged by an elastic fluid, in quick succession through a gun barrel: but with this difference, that the gaseous

molecules propel each other; instead of being, like the bullets, propelled by a foreign agency. The explanation now offered of the passage of the molecules of a gas through a narrow canal, or through any porous matter, may, as we have said, be applied, not only to the passage of light and heat through various media; but also to the passage of liquids through various bodies, by the processes which have been termed *endosmose* and *exosmose*. Do these forces operate also in capillary attraction?

Page 131.—TABLE OF TEMPERATURES.—(FROM

Isothermal Zones.	Names of Places.	Position.			Mean Temperature of the Year.
		Latitude North.	Longitude.	Height in Feet.	
Isothermal Zones from 32° to 41°.	Nain	57° 8′	61°20′W	0	26.42°
	*Enontekies	68 30	20 47 E	1356	26.96
	Hospice de St. Gothard	46 30	8 23 E	6390	30.38
	North Cape	71 0	25 50 E	0	32.00
	*Uleo	65 3	25 26 E	0	35.08
	*Umeo	63 50	20 16 E	0	33.26
	*St. Petersburg	59 56	30 19 E	0	38.84
	Drontheim	63 24	10 22 E	0	39.92
	Moscow	55 45	37 32 E	970	40.10
	Abo	60 27	22 18 E	0	40.28
Isothermal Zones from 41° to 50°.	*Upsal	59 51	17 38 E	0	42.80
	*Stockholm	59 20	18 3 E	0	42.26
	Quebec	46 47	71 10 W	0	41.74
	Christiana	59 55	10 48 E	0	42.08
	*Convent of Peysenburg	47 47	10 34 E	3066	42.98
	*Copenhagen	55 41	12 35 E	0	45.68
	*Kendal	54 17	2 46 W	0	46.22
	Malouine Islands	51 25	59 59 W	0	46.94
	*Prague	50 5	14 24 E	0	49.46
	Gottingen	51 32	9 53 E	456	46.94
	*Zurich	47 22	8 32 E	1350	47.84
	*Edinburgh	55 57	3 10 W	0	47.84
	Warsaw	52 14	21 2 E	0	48.56
	*Coire	46 50	9 30 E	1876	48.92
	Dublin	53 21	6 19 W	0	49.10
	Berne	46 5	7 26 E	1650	49.28
	*Geneva	46 12	6 8 E	1080	49.28
	*Manheim	49 29	8 28 E	432	50.18
	Vienna	48 12	16 22 E	420	50.54

(*) At the Places thus distinguished, the Temperatures

ENCYCLOPŒDIA METROPOLITANA.—ARTICLE METEOROLOGY.)

Distribution of Heat in the different Seasons.				Maximum and Minimum.	
Mean temp. of Winter.	Mean temp. of Spring.	Mean temp. of Summer.	Mean temp. of Autumn.	Mean temp. of warmest Month.	Mean temp. of coldest Month.
—0.60°	23.90°	48.38°	33.44°	51.80°	—11.28°
+0.68	24.98	54.86	27.32	59.54	—0.58
18.32	26.42	44.96	31.82	46.22	+15.08
23.72	29.66	43.34	32.08	46.58	22.10
11.84	27.14	57.74	35.96	61.52	7.70
12.92	33.80	54.86	33.44	62.60	11.48
17.06	38.12	62.06	38.66	65.66	8.60
23.72	35.24	61.24	40.10	64.94	19.58
10.78	44.06	67.10	38.30	70.52	6.08
20.84	38.30	61.88	40.64	———	———
24.98	39.38	60.26	42.80	62.42	22.46
25.52	38.30	61.88	43.16	64.04	22.82
14.18	38.84	68.00	46.04	73.40	13.81
28.78	39.02	62.60	41.18	56.74	28.41
28.58	42.08	58.46	42.98	59.36	30.20
30.74	41.18	62.60	48.38	65.66	27.14
30.86	45.14	56.84	46.22	58.10	34.88
39.56	46.58	53.06	48.46	55.76	37.40
31.46	47.66	68.90	50.18	———	———
30.38	44.24	64.76	48.74	66.38	29.66
29.66	48.20	64.04	48.92	65.66	26.78
38.66	46.40	58.28	48.56	59.36	38.30
28.76	47.48	69.08	49.46	70.34	27.14
32.36	50.00	63.32	50.36	64.58	29.48
39.20	47.30	59 54	50.00	61.16	35.42
32.00	48.92	66.56	49.82	67.28	30.56
34.70	47.66	64.94	50.00	66.56	34.16
38.80	49.64	67 10	49.82	68.72	33.44
32.72	51.26	69.26	50.54	70.52	26.60

given are the result of at least 8000 observations.

TABLE OF TEMPERATURES.

Isothermal Zones.	Names of Places.	Position.			Mean Temperature of the Year.
		Latitude.	Longitude.	Height in feet	
Isothermal Zones from 50° to 59°.	*Clermont	45°46′	3° 5′E	1260	50.00°
	*Buda	47 29	19 1 E	494	51.08
	Cambridge,(U. S.)	42 25	71 3 W	0	50.36
	*Paris	48 50	2 20 E	222	51.08
	*London	51 30	0 5 W	0	50.36
	Dunkirk	51 2	2 22 E	0	50.54
	Amsterdam	52 22	4 50 E	0	51.62
	Brussels	50 50	4 22 E	0	51.80
	*Franeker	52 36	6 22 E	0	51.80
	Philadelphia	39 56	75 16 W	0	53.42
	New York	40 40	73 58 W	0	53.78
	*Cincinnati	39 6	82 40 W	510	53.78
	St. Malo	48 39	2 1 W	0	54.14
	Nantes	47 13	1 32 W	0	54.68
	Pekin	39 54	116 27 E	0	54.86
	*Milan	45 28	9 11 E	390	55.76
	Bordeaux	44 50	0 34 W	0	56.48
Isothermal Zones from 59° to 68°.	Marseilles	43 17	5 22 E	0	59.00
	Montpellier	43 36	3 52 E	0	59.36
	*Rome	41 53	12 27 E	0	60.44
	Toulon	43 7	5 50 E	0	62.06
	Nangasacki	32 45	129 55 E	0	60.80
	*Natchez	31 28	90 30 W	180	64.76
Isothermal Zones from 68° to 77°.	*Funchal	32 37	16 56 W	0	68.54
	Algiers	36 48	3 1 E	0	69.98
Isothermal Zones above 77°.	*Cairo	30 2	31 18 E	0	72.32
	*Vera Cruz	19 11	96 1 W	0	77.72
	*Havannah	23 10	82 13 W	0	78.08
	*Cumana	10 27	65 15 W	0	81.86

* At the places thus distinguished, the Temperatures

(CONTINUED.)

Distribution of Heat in Different Seasons.				Maximum and Minimum.	
Mean temp. of winter.	Mean temp. of spring.	Mean temp. of summer.	Mean temp. of autumn.	Mean temp. of *warmest* Month.	Mean temp. of *coldest* Month.
34.52°	50.54°	64.40°	51.26°	66.20°	28.04°
33.98	51.08	70.52	52.34	71.60	27.78
33.98	47.66	70.70	49.82	72.86	29.84
38.66	49.28	64.58	51.44	65.30	36.14
39.56	48.56	63.14	50.18	64.40	37.76
38.48	48.56	64.04	50.90	64.76	37.75
36.86	51.62	65.84	51.62	66.92	35.42
36.68	53.24	66.20	51.08	67.28	35.60
36.68	51.08	67.28	54.32	69.08	32.90
32.18	51.44	73.94	56.48	77.00	32.72
29.84	51.26	79.16	54.50	80.78	25.34
32.90	54.14	72.86	54.86	74.30	30.20
42.26	52.16	66.02	55.76	66.92	41.74
40.46	54.50	68.54	55.58	70.52	39.02
26.42	56.30	82.58	54.32	84.38	24.62
36.32	56.12	73.04	56.84	74.66	36.14
42.08	56.48	70.88	56.30	73.04	41.00
45.50	57.56	72.50	60.08	74.66	44.42
44.06	56.66	75.74	60.98	78.08	42.08
45.86	57.74	75.20	62.78	77.00	42.26
48.38	60.80	75.02	64.40	77.00	46.40
39.38	57.56	82.94	64.22	86.90	37.40
48.56	65.48	79.16	66.02	79.70	46.94
64.40	65.84	72.50	72.32	75.56	64.04
61.52	65.66	80.24	72.50	82.76	60.08
58.46	73.58	85.10	71.42	85.82	56.12
71.96	77.90	81.50	78.62	81.86	71.06
71.24	78.98	83.30	78.98	83.84	69.98
80.24	83.66	82.04	80.24	84.38	79.16

given are the result of at least 8000 observations.

Page 163, *Note.*—We have stated that the diffusion of the same air, and of the same vapour at different temperatures, are inferences only from the supposed general law of the diffusion of gaseous bodies; and have alluded to the existence of modifications of that general law. To those who feel an interest in such inquiries, the following additional remarks may be not unacceptable, as pointing out the grounds from which we infer such diffusion of the same air and vapour; and the modifications, to which we have no doubt, it will be found to be liable.

Let us suppose a flexible air-tight bag to be furnished with a stop-cock; and to be filled with hydrogen gas, under exactly the same pressure, and having the same temperature as the surrounding atmosphere. Let us now suppose the stop-cock to be opened. Immediately, the hydrogen in the bag, and the exterior atmospheric air, will begin to commingle, with a force and velocity proportional to the quantity of the gas diffused; and which quantity varies inversely as the square roots of the specific gravities of hydrogen gas, and of atmospheric air; that is to say, the volume of atmospheric air diffused inwards, being supposed to be equal to 1, the volume of hydrogen diffused outwards, will be equal to 3.8 nearly. The diffusion of hydrogen and atmospheric air of the same temperature, and under the same pressure, is an instance of the simplest form of gaseous diffusion; and is, we believe, the only form of diffusion, which has been experimentally investigated. The phenomena attending the diffusion of these two bodies show, that, all other circumstances being supposed to be alike, the diffusion of gases is influenced solely by the difference of their specific gravities.

We have stated the case of the diffusion of two gaseous bodies having the *same* temperature. Their temperature however, may vary within any limits; and though the law of diffusion may be modified, diffusion will continue to take place, (except at those temperatures at which the specific gravities of the two gases become equal, at which temperatures there will be no tendency to diffusion); provided difference of specific gravity alone be the cause of diffusion. But if the diffusion of different gases at different temperatures be admitted, it seems to follow, that different portions of the *same* gaseous body under the same pressure, but having different temperatures, and consequently different specific gravities, will likewise have a tendency to diffusion.

The case we shall next suppose is dissimilar to the two foregoing cases, but is deducible from the same premises; it is the case of the diffusion of the same vapour, as of the vapour of water, which may be illustrated in the following manner:

Let us suppose our apparatus to contain atmospheric air, having the temperature of 100°, and saturated with water; while

the exterior atmospheric air is at the temperature of 60°, and is likewise saturated with water; and that the pressure on the air confined in the bag, is the same as the external pressure. We suppose the presence of air in the apparatus, in order that it may be able to sustain the atmospheric pressure; for, as we formerly stated, vapour alone, at ordinary temperatures, exerts elastic forces very different from, and far inferior to the elastic force of air at these temperatures. Such being supposed to be the state of the air contained in our apparatus, what will happen on the opening of the stop-cock? The air within the bag will have the same tendency to diffusion, as the contents of the bag supposed in the last case; but the vapour with which the air is associated will have an opposite tendency. The warmer vapour within the apparatus, instead of being, like the warmer air, lighter; will have a greater specific gravity than the colder vapour associated with the external air. Consequently, the inward tendency to diffusion, that is to say, the tendency of the colder vapour without the apparatus, to diffuse itself among the molecules of the warmer vapour within will be greater than the outward diffusive tendency of the vapour in the apparatus. Such will be the opposing diffusive tendencies of warm vapour and of warm air in a state of commixture; and if the air were absent, the diffusive tendency of vapour alone would have a similar diffusive tendency to that which it has, when mixed with air; though that tendency would, of course, be not exactly the same as when modified by the influence of the air. The vapour within, and the vapour without the apparatus, would each exert the elastic forces peculiar to their respective temperatures as vapour.

There would, however, be a striking difference between the phenomena attending the diffusion of vapour, (whether mixed or unmixed with air), and that of air itself at different temperatures. Two portions of air at different temperatures would cease to have any diffusive tendencies as soon as their temperatures became uniform. The temperature of two portions of vapour becoming uniform, would, of course, produce, in the same manner, a cessation of their diffusive tendencies; but the circumstances accompanying that cessation would be altogether different. The colder vapour without the apparatus, being the lighter, would move with accelerated velocity into, or toward, the heavier warm vapour within the apparatus; while that warm vapour, in moving outward, would be instantly condensed; and thus its diffusive powers would be annihilated. On these grounds we advanced the opinion, that *probably*, there may, under certain circumstances, exist in the atmosphere, a tendency to diffusion from above downwards; the vapour in the higher regions of the atmosphere, being relatively lighter than the vapour below.

The observations that have been offered in this note, regard the only circumstance which is yet known to cause a difference in this diffusive tendency of gaseous bodies, namely, the difference of their specific gravities. If there be other causes of such difference ; and it is almost certain that there is *one* other cause ; the effects produced by these causes may be very different. The difference in the diffusive power of the same gaseous body, is not perhaps, under any circumstances, very remarkable ; but there will probably be found to be a much greater difference in the diffusive power of vapours ; though it is not easy to form even a conjecture as to the extent of that difference. In the present state of uncertainty therefore on those points, we have thought it right to speak of a *tendency* to diffusion, rather than of diffusion, as a thing actually existing. The diffusive powers of elastic fluids are at present very little understood or appreciated. They constitute, however, as we have said, one of the most interesting and important subjects in physics, and would amply repay whoever would take the trouble to investigate them.

Page 207.—The table follows, illustrating the distribution of plants over the globe, to which we have referred in the text. It has been copied immediately from Lindley's Introduction to Botany.

Groups.	Proportion to the whole mass of Phænogamous Plants.		
	Equatorial Zone. Lat. 0°—10°.	Temperate Zone, Lat. 45°—52°.	Frozen Zone, Lat. 67°—70°.
Agamæ *(Ferns, Lichens, Mosses, Fungi)*	Plains $\frac{1}{15}$; Mountains $\frac{1}{5}$	$\frac{1}{2}$	$\frac{1}{1}$
Ferns alone	Countries nearly flat $\frac{1}{20}$; Countries very mountainous $\frac{1}{3}$ to $\frac{1}{8}$	$\frac{1}{70}$	$\frac{1}{25}$
Monocotyledones	Old Continent $\frac{1}{5}$; New Continent $\frac{1}{6}$	$\frac{1}{4}$	$\frac{1}{3}$
Glumaceæ *(Juncæ, Cyperaceæ, Gramineæ)*	$\frac{1}{11}$	$\frac{1}{8}$	$\frac{1}{4}$
Junceæ alone	$\frac{1}{400}$	$\frac{1}{90}$	$\frac{1}{25}$
Cyperaceæ alone	Old Continent $\frac{1}{22}$; New Continent $\frac{1}{50}$	$\frac{1}{20}$	$\frac{1}{9}$
Gramineæ alone	$\frac{1}{14}$	$\frac{1}{12}$	$\frac{1}{10}$
Compositæ	Old Continent $\frac{1}{18}$; New Continent $\frac{1}{12}$	Old Continent $\frac{1}{8}$; New Continent $\frac{1}{6}$	$\frac{1}{13}$
Leguminosæ	$\frac{1}{10}$	$\frac{1}{18}$	$\frac{1}{35}$
Rubiaceæ	Old Continent $\frac{1}{14}$; New Continent $\frac{1}{25}$	$\frac{1}{60}$	$\frac{1}{800}$
Euphorbiaceæ	$\frac{1}{32}$	$\frac{1}{80}$	$\frac{1}{500}$
Labiatæ	$\frac{1}{40}$	America $\frac{1}{40}$; Europe $\frac{1}{25}$	$\frac{1}{70}$
Malvaceæ	$\frac{1}{35}$	$\frac{1}{200}$	$\frac{0}{0}$
Ericeæ	$\frac{1}{130}$	Europe $\frac{1}{100}$; America $\frac{1}{36}$	$\frac{1}{25}$
Amentaceæ	$\frac{1}{800}$	Europe $\frac{1}{45}$; America $\frac{1}{25}$	$\frac{1}{20}$
Umbelliferæ	$\frac{1}{500}$	$\frac{1}{40}$	$\frac{1}{600}$
Cruciferæ	$\frac{1}{800}$	Europe $\frac{1}{18}$; America $\frac{1}{60}$	$\frac{1}{24}$

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